PITMAN'S
MASTERY SERIES

# THE MASTERY OF WATER

THE FALLS OF NIAGARA.

[*Frontispiece*

*PITMAN'S MASTERY SERIES*

# THE MASTERY OF WATER

BY

THE AUTHOR OF

THE TRIUMPH OF MAN

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# PREFACE

THIS little book is one of four on *The Mastery of Earth, The Mastery of Air, The Mastery of Fire,* and *The Mastery of Water.* They take their titles from the " four elements" of the Greek philosophers, and they seek to tell how Man has acquired a " mastery " both in the sense of understanding, and in the sense of using for his own benefit. They offer such scientific explanations as are necessary, supply such history as is desirable, and describe such applications as are appropriate for boys and girls who, born in these later years, enter a world so rich and varied that it compels attention, so complex that it defies analysis.

The author's object has been, in the first instance, to suggest interests rather than to satisfy needs. He has tried to exhibit something of the range of human knowledge and the variety of human activity. He has endeavoured to present science not merely as a subject of the study, but also as a vital force in the field, the factory, and the mine. In a word, he has striven to show how scientific knowledge is blended with imagination and enterprise in promoting the welfare and progress of mankind.

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# THE MASTERY OF WATER

## SECTION I

### INTRODUCTION.

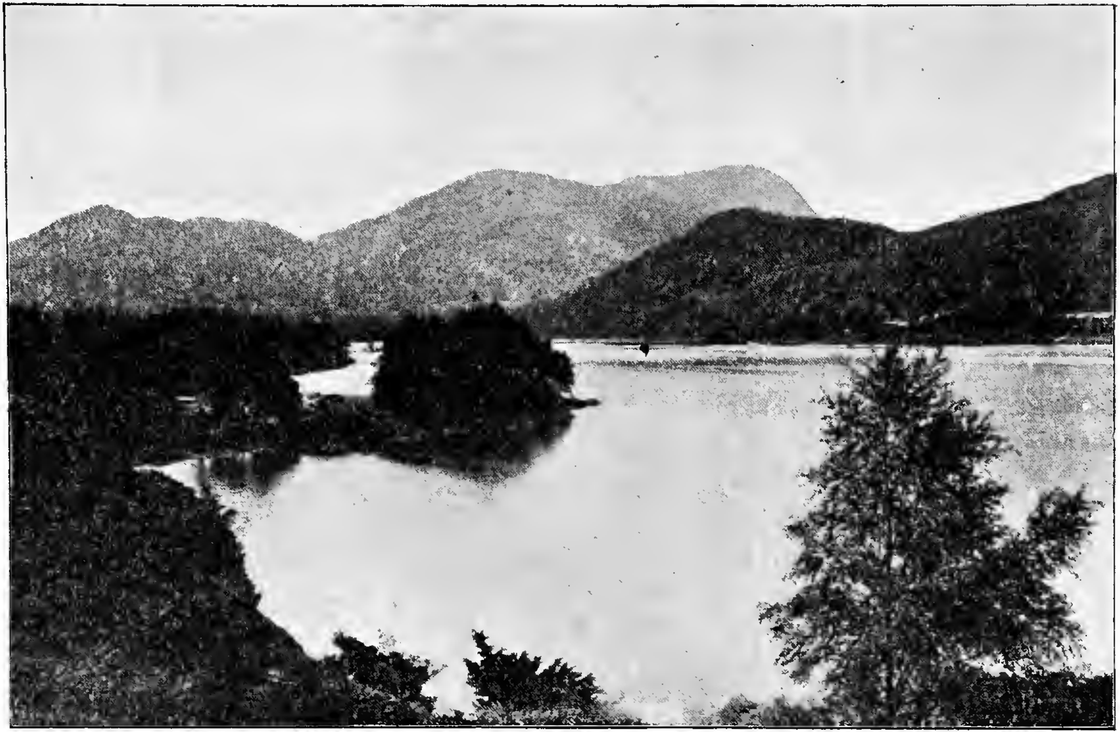
Of all the commonest substances round about us there is none more important than water. It forms a considerable proportion of the human body, and a certain amount must be drunk daily to take the place of that which passes away from the surface, in the form of vapour. Without water we should shrivel up like the dead leaves in a dry autumn. The absence of good water and the presence of bad are alike responsible for disease. An abundant supply of pure water is essential, not only to cleanliness and health, but to the very existence of man on the earth.

From the beginning of the long struggle with the forces of Nature, water was the first element which had to be subdued—or, if not subdued, at least controlled. The first men learned that it was quite as valuable, and quite as dangerous as fire—that it could be a good servant and a bad master. It was necessary to their crops, and had the power of making the dry, parched earth fresh and green and fruitful; but in the time of flood it poured over the land with irresistible force, sweeping everything before it and destroying the labour of many months. As observation taught him what to expect, man rose with the light of battle in his eyes, and laid cunning schemes to protect his property from the enemy which appeared so suddenly and created such havoc in its path.

Here, indeed, was the nursery of those engineering

triumphs which have played such a large part in modern civilisation. The two nations of antiquity of which the fullest records have been preserved were the Babylonians and the Egyptians, and both owed their growth and power to their control of the same force which threatened them in different ways. The former flourished in the low-lying land around the lower courses of the Tigris and Euphrates. From time to time these rivers overflowed their banks and washed away every vestige of man's handiwork. Of water the Babylonians were never short: their trouble was that occasionally they had too much. The ancient Egyptians, on the other hand, settled in the Nile valley beyond Thebes, and grew their crops in the fertile mud brought down by the river and spread over the valley which it flooded every year. Now and then the river failed to rise to a sufficient height, and then there was famine in the land. The menace of Babylon was flood; the sword that hung over Egypt was drought; and in both cases great works were constructed to bring natural forces under the control of the human will.

Long afterwards, other nations profited by experience and entered upon vast undertakings with the same object. The struggle has been carried on for about 10,000 years, with many a rebuff but always with final victory. Nor is it in this way alone that water has been made to serve man. Since the time when a floating log first suggested an easy means of locomotion, transport by water has developed until it is as speedy, as safe, and nearly as comfortable as on land. The oceans have been charted, rivers have been made navigable, and enormous canals have been engraved on the face of the earth. The largest ships can to-day pass from coast to coast, and climb hills that a locomotive can surmount only by pursuing a winding path.



A PLACID LAKE.

Again, in his frequent and persistent efforts to escape from manual toil, and to accomplish tasks beyond the power of the patient ox, man made use of water. Delivered along carefully constructed channels, it turned a wheel, ground his corn, and drove the machines by means of which delicate fabrics were woven. Then, for a time, it gave way to the steam engine, which used water in another form. And now, with the dawn of a new century, it is again becoming of increasing importance as a source

A FLOOD IN THE FENS.

of power so—much so, that new industries are springing up in the neighbourhood of great waterfalls, which threaten to rival, and perhaps displace, the coalfields as centres of population.

The story of man's conquest of water is the story of his long and painful growth from savagery to civilisation. If you gaze into the placid waters of a beautiful lake you can picture to yourself the periods of quiescence, when a truce has been called and man and nature have rested from the struggle. If you stand on the deck of

a noble vessel and watch the heavy swell in threatening weather, you can imagine that you hear the hoarse, muffled growl of a giant about to break loose. A glance at the scarred face of the cliff will give a faint indication of what he can do when in an angry mood. But to realise fully the power of water you must be out in a violent storm ; see a great ship cast upon the rocks ; witness, as I have done, a stretch of smiling country covered by a roaring flood, which has thrown down stone walls and carried away bridges as though they were children's toys. It is then that man feels his helplessness, then that, crushed, but not beaten, he braces himself up and takes heart for a fresh campaign on the morrow. For in the struggle there is life and death, joy and sorrow, victory and defeat ; there are many who fall by the way, many who give up in despair ; but their places are taken by others, and the enemy is once more brought under control. The very atmosphere is electrical with Romance, and what more can we ask ?

# SECTION II

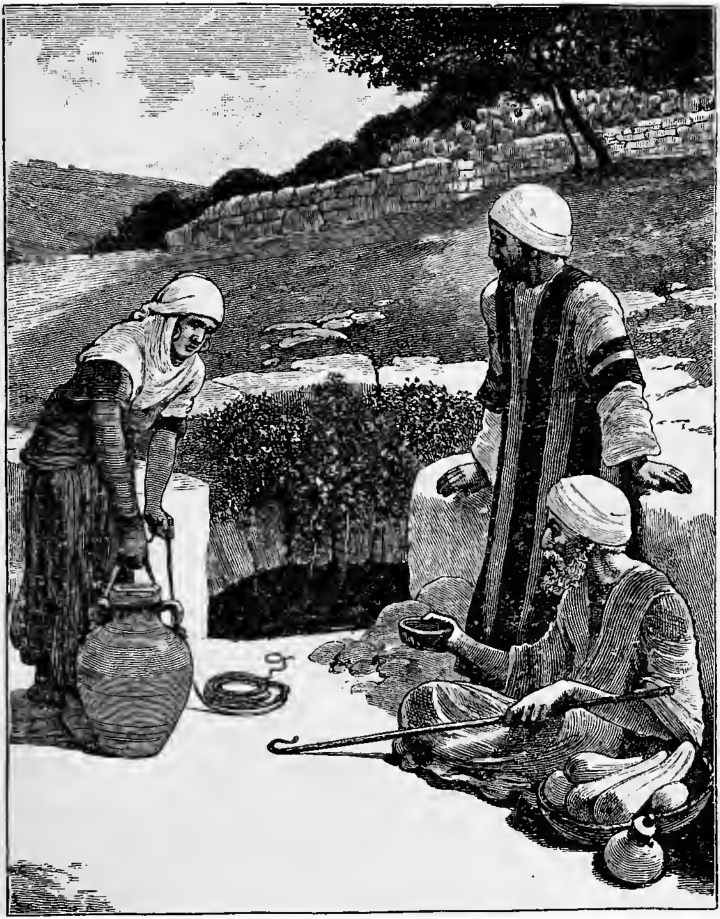
## THE THIRST OF THE CITY.

### CHAPTER I.

### Water Supplies.

One of the greatest comforts of modern towns is the privilege of living in houses to which water is laid on, so that it can be had merely for the effort of turning a tap. In fact it is so easily obtained that people are apt to forget its value. They have a hazy notion, perhaps, that at one time the water needed for drinking and household purposes had to be fetched from a spring or well, and they are often aware that the water supply of a town adds very considerably to the rates. But they are generally quite ignorant of the source of the town's supply, of the trouble to which men went to establish it, and of the debt they owe to the foresight, skill, and perseverance of the pioneers.

One of the most surprising things about water supply is the amount which is now required, compared with the amount used before the big schemes of the last hundred years were established. When Manchester people were beginning to feel the need of more water early in the nineteenth century, they spoke of ten gallons per head per day. Soon afterwards the estimate rose to twenty-five gallons. Towns vary very much in their requirements, because in some cases the workshops and factories take a great deal, but from seventy to one hundred gallons per head per day is now usually considered to be necessary.



AN EASTERN WELL.

This amount, however, is very often exceeded. An inquiry which was conducted recently into the quantities used in the nine largest cities of the United States gave the following results—

| | | | | |
|---|---|---|---|---|
| St. Louis, | 100 | gallons per | head, | per day. |
| Baltimore, | 119 | ,, | ,, | ,, |
| New York, | 120 | ,, | ,, | ,, |
| Cleveland, | 123 | ,, | ,, | ,, |
| Boston, | 130 | ,, | ,, | ,, |
| Cincinnati, | 141 | ,, | ,, | ,, |
| Chicago, | 204 | ,, | ,, | ,, |
| Philadelphia, | 218 | ,, | ,, | ,, |
| Buffalo, | 322 | ,, | ,, | ,, |

Is it not surprising that, while the people in some towns can manage with, say, sixty gallons a day each, those in other towns require five times as much? The difference is accounted for partly by manufactures, partly by extravagance, and partly by leakage in the mains. Extravagance is being checked by the use of water meters. It is found that when people have to pay for just what they use they are much more careful to avoid waste. The loss by leakage is being stopped in some towns by a regular system of testing, which enables the leak to be detected at once and measures to be taken to stop it. In Washington this plan alone has led during the last few years to a reduction of the total amount, even though the population has been increasing.

In Liverpool there are two inspectors out every night hunting for sources of waste. They carry an iron bar, which they rest against the pipes leading to each block of houses, and by placing an ear to the other end they are able to ascertain whether water is flowing or not. If water is flowing it is usually doing so because of a

defective tap, or because a tap has been left on. On returning to the office in the early morning reports are handed in, and the day inspectors investigate each case. One result of this is that the consumption is under thirty gallons per head per day.

Quite apart from health and cleanliness and the conduct of manufacture, the greatest usefulness of a plentiful supply of water is in putting out fires. In the Middle Ages many English towns were built of wood, and when a fire started it spread from street to street with terrible rapidity. You will remember, for example, the Great Fire of London in 1666. Even to-day many a fire would be far less disastrous if the water supply were better. We must not forget that fire was to some extent an advantage in olden times because it killed off the germs of disease; but these germs were often present owing to the water being insufficient or of bad quality. And it is better to have plenty of good water and use other methods of keeping away disease than to have to be cleansed every now and then by fire.

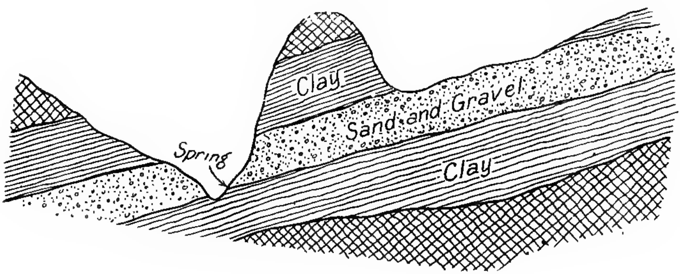
## CHAPTER II.

### The Waters Under the Earth.

MAN probably welcomes the river, the lake, and the sea as means of freshening his body before or after the labours of the day; but for drinking he prefers the clear, crystal spring which gushes from the hillside. For one thing, the water is generally colder, and in warm weather when thirst is keener this is an advantage. If you have read the volume on the *Mastery of Earth*, you may wonder why spring water is often so cold, although the

temperature of the earth increases as one goes downwards. But this increase is very small; and at moderate distances below the surface the ground is nearly always warmer in winter and colder in summer than the air above.

Spring water is clear because all the suspended particles have been filtered out in its passage through the ground; and it is often sparkling because of the gas which it has dissolved at great depths under pressure, and which is liberated in minute bubbles as the water escapes from




HOW SPRINGS ARE FORMED.

its rocky prison. But, before we go into a question of this kind it will be well to consider how springs arise. When rain falls upon the land, some of it sinks through the surface, some is evaporated and carried away by the wind, some is sucked up by the roots of plants, and some runs off into a river and so into the sea. What proportion goes in each direction is very important, and no doubt it varies very considerably in different districts. The engineer who proposes to supply a town with water wants exact information on the matter. From measurements which have been carried out recently, it has been shown that about fifty per cent. sinks into the ground,

ten per cent. is evaporated or absorbed by plants, and forty per cent. runs back to the sea. We shall follow up that which sinks into the ground.

The rocks of which the earth's crust is composed are more or less porous, so that water can sink through them. This is, of course, easily understood in regard to beds of soft sandstone or limestone ; but even the harder varieties have a network of cracks which provide an easy passage for the water. Clay, on the other hand, refuses to allow water to pass at all. It is one of the most mysterious of all the wonderful materials which compose the earth. The particles of which it is composed are very small—in true clays not more than $\frac{1}{125000}$ of an inch in diameter. When clay is dry it becomes brittle and can be broken up by a blow, but on being moistened it swells up and becomes soft and plastic, so that it can be moulded into any form. The more thoroughly it is kneaded with water the more "watertight" does it become ; it has for ages been used for lining ponds and canals. Clay which has been well worked with water is called "puddled clay," or simply "puddle." Suppose, now, a permeable rock like sandstone lies over a bed of clay. Water will sink through the upper bed until it reaches the lower, when it will go no farther. For a time the upper rock will hold the water like a sponge ; but as more rain falls it will trickle out at any place where the edge is exposed. The layers of rock, or *strata*, are rarely horizontal, and the spring will usually be formed at the lower end only. Such a spring would only run for a time after rainy weather, unless the area covered was very large ; and, as a matter of fact, there is in nearly all springs a marked difference between the amount of flow at different seasons.

A spring often forms the source of a river, and, as the rivulet makes its way towards the sea, it is joined by

many others on each side, which may themselves have their origin in similar springs. At the same time a river is fed by a good deal of ordinary surface drainage in wet weather, when the ground becomes soaked and the water runs off to a lower level without passing along the ordinary channels. This represents the forty per cent. to which reference was made a page or two back.

But to return to springs. As the water soaks through the rocks it dissolves something from them, and in some cases this dissolved matter amounts to a good deal. Thus the air always contains a small amount of carbon dioxide—about 4 parts in 10,000, by volume—and some of this is dissolved by the rain. Water containing carbon dioxide in solution is capable of dissolving calcium carbonate, of which limestone and marble are composed. If the water evaporates or is boiled away, calcium carbonate is deposited. This is the cause of the pillars, called *stalagmites* (rising from the ground) and *stalactites* (hanging like icicles from the roof) in the caves in limestone districts.

The calcium carbonate can be removed by simply boiling the water and thus driving off the carbon dioxide —the calcium carbonate then appears as a fine white powder which slowly settles to the bottom. If soap is used before the water is boiled, the calcium carbonate forms a scum which floats on the surface, and until sufficient has been formed to remove the carbonate, no lather can be produced. The water is said to be "hard," and the hardness in this case is called "temporary hardness" because it can be so easily removed. Destroying the hardness of water is called "softening."

Another kind of hardness is produced by the presence of calcium sulphate, which is known to the geologist as "gypsum." This will dissolve slightly in water whether

carbon dioxide is present or not, and cannot be wholly removed by boiling unless practically all the water is boiled away. It has the same action on soap as the carbonate, and is therefore equally objectionable. Water containing it is said to be "permanently hard."

Very hard water is undesirable for domestic purposes and for manufactures, because it makes the "fur" in the kettle and deposits a scale on the inside of steam boilers. Sometimes expensive apparatus has to be set up to soften water, whichever kind of hardness is present. The simplest process for removing permanent hardness consists in adding sodium carbonate to the water in exactly the amount which has been calculated to be necessary. This makes an exchange with the calcium sulphate, forming calcium carbonate, which is precipitated, and sodium sulphate. The sodium sulphate remains in the water, but, as it does not form a curd with soap and is not harmful, this does not matter.

It would be expensive to remove the temporary hardness of a large quantity of water by boiling, so this is softened by a method which will be easily understood. You will remember that the calcium carbonate is held in solution by the presence of carbon dioxide. A small quantity of lime is added to the water, and this combines with the carbon dioxide to form a further quantity of calcium carbonate, which is thrown out of solution with that originally present. So much for the science of the bath!

Springs whose waters flow through rocks containing iron often contain a small quantity of this substance. It can be easily recognised by the yellowish-brown colour of the water, and the fact that the stones and soil over which it flows are tinged with this colour. The stain is also given to a handkerchief or any other

light-coloured fabric, and is then familiarly spoken of as iron-mould. Compounds of iron are useful in medicine, and the water of these springs is supposed to be valuable in many complaints. There is, in fact, a great number of medicinal springs, and health resorts, or "spas," have been built in the neighbourhood in which they occur. Examples in England are Harrogate and Woodhall Spa; but to follow this up further would take us outside the scope of this book. It is sufficient to say that the knowledge which man has acquired about spring waters has enabled him to use them to relieve suffering and restore health. Let us now see how the needs of a great city were supplied from springs more than 300 years ago.

## CHAPTER III.

### The Romance of the New River.

ONE of the schools built by the London School Board towards the close of the nineteenth century was called "The Hugh Myddelton Higher Grade School." How many of those who attend know who Hugh Myddelton was, when he lived, and what he did to deserve the honour which has been paid to him? If we wish to know about these things we must go back to the time when James I was King, when we shall find that he was a London goldsmith, with many other interests in life besides the buying and selling of gold and silver. He was a friend, for example, of Sir Walter Raleigh, and had a brother who was captain of a ship which made many voyages to the Spanish Main. Perhaps these facts drew him into the wider field of Commerce and encouraged him to set up as a cloth manufacturer, and also to become

one of the Merchant Adventurers whose enterprises had so much to do with the growth of English trade.

HUGH MYDDELTON.

Hugh Myddelton was born near Denbigh in 1555, and after completing his education he was sent to London and apprenticed to a goldsmith. His business prospered,

and having become a man of some wealth he represented his native town in Parliament from 1603. At that time London was a town of 150,000 inhabitants, living in about 17,000 houses. These were brick below and timber above, with the first floors overhanging so far that they nearly met across the narrow streets. There were no carriages in England in those days, all travelling being done on foot or on horseback, so the narrowness of the streets did not interfere with trade. Trade was growing; there were frequent fires and outbreaks of fever and plague; and the Corporation was sorely troubled about the need for water. An Act of Parliament was passed, empowering the Aldermen and Burgesses of the city to arrange for a fresh supply, but no one would undertake the work. At last Hugh Myddelton volunteered to do it, and the Corporation granted permission on condition that he finished the work within four years. In May, 1609, he made a beginning.

The sources of supply were two springs, a little more than twenty miles away from the city, the chief one being at Chadwell, near Ware, and the other at Amwell, close by. The plan was to cut a ditch, keeping this as much as possible on level ground, but with a fall of about two inches per mile towards the circular pond at Clerkenwell. Where the ground fell too rapidly, a gate or weir, three or four feet high, was interposed, and the cut, or "New River," as it was called, continued below. Here and there it was necessary to carry the stream over a road, when arches or lead-lined troughs of timber would be used. There was originally one at Bush Hill, near Edmonton, 660 feet long, and five feet deep; and another, nearer Islington, was 460 feet long and seventeen feet above the ground. At Islington there was a tunnel about five feet by three feet, and there was another at

Stoke Newington. The task had been by no means an easy one.

It was, of course, necessary to prevent, as far as possible, surface water from running into the river, because that is hardly ever fit for drinking purposes. So, where the cut wound round the hill-sides, arrangements had to be made either to carry the surface waters from the higher ground over it, or to shoot them underneath it. The windings of the channel were so numerous that the total length was thirty-eight and three-quarter miles, or nearly double the distance of the wells from Islington as the crow flies.

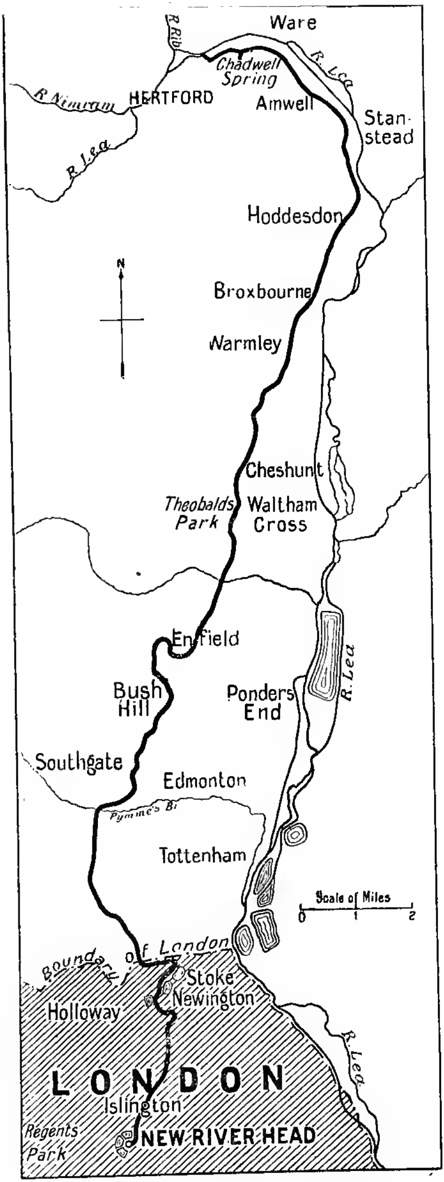
The constructor soon had a foretaste of the kind of opposition that, over two hundred years later, was waged so fiercely against railways and other public works. The owners and occupiers of land in the neighbourhood of the river took every means to hinder the scheme, on the ground that it interfered with the drainage of their land, robbed them of water, or created undesirable bogs. But Myddelton was acting under instructions from the Corporation of the City of London, who had their powers from Parliament; so he stuck to his guns, and kept on with his project. Finding that strong measures would be necessary to stop him, the landowners introduced a Bill into Parliament in 1611, but before it could be passed the House was prorogued and it did not meet again for four years; by that time the work was completed. This was an advantage which Myddelton could not have enjoyed in these days of continuous parliaments!

Before the four years allowed for the work were up it became clear that the canal would not be completed in time, and Myddelton had to ask the Corporation to grant him an extension of time. They allowed him five years. Then another and more serious difficulty arose: he became short of money. How this might have been

overcome in ordinary circumstances it would be hard to say; but in the course of his business as a goldsmith he had become known to the King. James I was interested in land drainage and similar matters, and had on a previous occasion given encouragement to the drainage of the Fens. At this stage he undertook to provide for half the cost of the work from the beginning; this, then, amounted to £4,485 18s. 11d. As the books of the company were destroyed by fire many years ago (fancy the books of a Water Company being destroyed by fire!), the total cost is not exactly known. The records of the Royal Treasury, however, show that £8,607 14s. 6d. was paid from that source, so that the total cost must have been about £18,000.

The New River was opened with great pomp and ceremony in 1613, and immediately began to supply the city with the water it needed so much. It was distributed through wooden pipes, of which at one time there were no less than 400 miles in use. They were very unsatisfactory in many ways, and people were suspicious of the wholesomeness of the water that came from them. Moreover, bad joints and decay led to great leakage, so much so that twenty-five per cent. of the water escaped in this way. As improvements were made in the casting of iron pipes, these were substituted for the wooden ones, and the loss was diminished.

Perhaps you will say, "Where is the Romance?" The Romance is bound up in the capital city of the greatest nation in the world. Without the precious waters of the New River, London could not have taken the steps by which it has reached its present size and importance. The New River, aided by the waters of the River Lea, and by innumerable wells about which we shall speak presently, enables seven millions of people to live in




MAP OF THE NEW RIVER.

health and cleanliness, with comparative freedom from disastrous fires. But if you want to know a little more about it, here you are.

You will remember that the cost was shared by Hugh Myddelton and the King. In 1619 a company was formed of which the capital was divided into seventy-two shares. Thirty-six of these were held by Myddelton and thirty-six by His Majesty. The original value of each share is now a little doubtful, but the most probable estimate is £250. The cost had fallen so heavily upon the man who had borne the burden and heat of the day that he sold thirty-four of his shares. For many years there was no profit at all, the first dividend of £15 3s. 4d. per share being paid in 1633. Three years then elapsed before the next dividend, which amounted to £3 4s. 2d.

At this stage, Charles I, who had entered into the legacy from his father, and who wanted money badly, gave up the whole of his shares to the company in return for an annual sum of £500 a year. But the corner had been turned, and after 1640 the shares regularly increased in value. By 1800 the dividend per share rose to £500, and by the middle of the nineteenth century it was £850. This is at the rate of at least 340 per cent. per annum; if you are interested in Arithmetic you may calculate how long it would take at this rate for a £5 note to produce a million.

## CHAPTER IV.

### Underground Water Basins.

In the early part of this section some explanation was given of the way in which springs are formed, and it was shown that they depended upon a sloping boundary

between an upper permeable, and a lower impermeable bed. But every one who has observed the layers of the earth's crust, as they are seen in a railway cutting or a quarry, knows that they are almost as frequently curved as straight. If, therefore, water falls on land beneath which the beds lie as in the sketch, it will collect in the basin or saucer formed by the lower impermeable bed. It is quite probable that springs will be formed at the outcrops of the porous bed, but that will occur only after a great deal of rain, and in a dry season they will give out altogether.

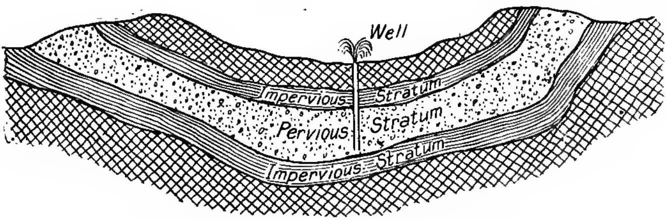



DIAGRAM OF AN ARTESIAN WELL.

If the water won't come to man, then man must go to the water; and he bores a deep hole down from the surface until he reaches the water. If the basin is a very deep one, the ordinary level of the water in it may be above the level of the ground in the middle, and the water will then squirt up until the level in the beds falls to that of the mouth of the well. But in many cases this does not happen, and the water has to be lifted by pumps. Before describing these, however, let us see how the well is bored.

In the first place it is necessary to distinguish between one of the wells we are about to describe and an ordinary, old-fashioned well like that of Jacob—though Jacob's

well was more probably a spring and not a well at all. An ordinary well is a hole dug in the ground very much like the shaft of a mine. It is made in porous ground and the water which this holds drains into it. Such a well is never very deep. Ours are 1,000, 2,000, 3,000 ft. or more. As there is always an advantage in having a name for a thing it may be stated that these wells are called "Artesian" wells, because they were first made at Artois, in France.

An artesian well is bored in the earth by rotating a steel tube, which has teeth or diamonds fixed in its lower edge. As the tube descends, a fresh length is fixed to the upper end, very much in the same way as a chimney-sweep increases the length of his brush. A fairly wide tube is used at first, and, when this becomes too heavy to rotate, a narrower one is lowered inside it, and then a narrower one still. When the water-bearing layers of rock are reached, the water often rises in a fountain, many feet high, and delivers hundreds of gallons of water per minute.

In order to give some idea of the importance of artesian wells we may consider the colony of Queensland, in which there were 1,879 wells in the year 1912. The depth varies from ten feet to 5,045 feet, the average being 1,081 feet. The Charleville bore is 1,371 feet deep and produces three million gallons a day. The water issues at a pressure of seventy-nine pounds on the square inch, and shoots up in a magnificent fountain, 100 feet in height. The total depth of the Queensland wells is 384·68 miles, and the total yield is 529,817,860 gallons per day.

There are many artesian wells in England, but they are generally most necessary in flat countries, where springs are rare, and the surface streams dry up in the hot season.

*By permission of the* *Queensland Government.*

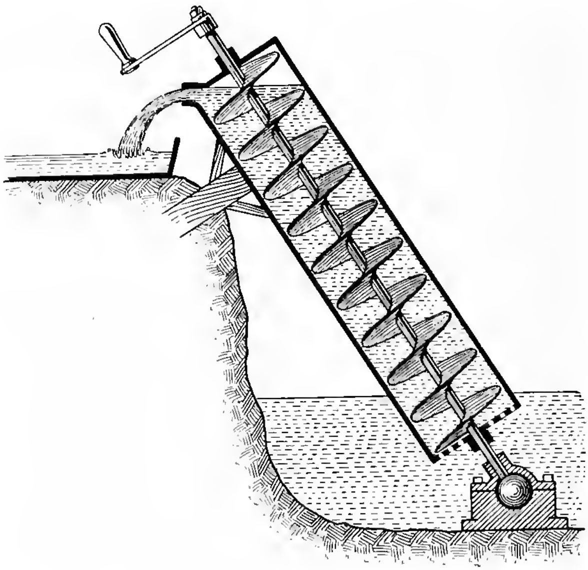
AN ARTESIAN WELL.

The Charleville Bore, Queensland.

## CHAPTER V.

### Pumps and How They Work.

If you were asked how long man has known how to pump water from one level to another, what would you say ? Before the steam engine, certainly, for we know



ARCHIMEDES' SCREW.

(The steepness of the slope is exaggerated in the diagram.)

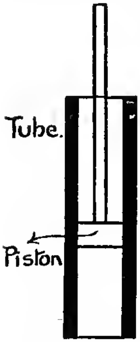
that it was the necessity for some form of power to get rid of the water in the mines that led to the struggle to invent a workable steam engine in the seventeenth and eighteenth centuries. Earlier, too, than Galileo and his

pupil Torricelli, who were interested in pumps nearly three hundred years ago. Earlier, to take a big jump backwards, than Archimedes, the clever old Greek of Syracuse, who lived about 200 B.C. More than a hundred years before that time, in the days of Aristotle, a lift pump was known.

Long before the Greeks, the people of Egypt and Babylonia were, as you know, concerned with water, but they had no pumps. The water from the Tigris, the Euphrates, and the Nile was raised in buckets, which were sometimes attached to an endless rope passing over the rim of a wheel, so that as the wheel turned the buckets alternately filled and emptied into a trough placed to receive their contents. In some places, the screw, the invention of which has been attributed to Archimedes, was employed. It consisted of a long shaft or spindle, upon which was fixed a spiral vane, which made several turns. This was made to rotate in a long wide tube, which was slanted so that its lower end was in the water, and its upper end over the top of the bank. As the screw was turned, it tended to worm its way into the water just as an ordinary screw works its way into wood. But, as the screw could not move forwards or backwards, the water was drawn up and flowed out at the top. A screw of this kind is used to-day for feeding material into a furnace, and for other purposes, but it is never used for raising water.

Now how does a pump work? Consider first an ordinary syringe. This consists of a tube, with a tightly fitting piston which is fixed at the end of a rod so that it can be moved backwards and forwards. If the piston is pushed to the lower end of the tube, and that end is placed beneath the surface of the water, and then the piston is drawn up, water will enter the tube. When the

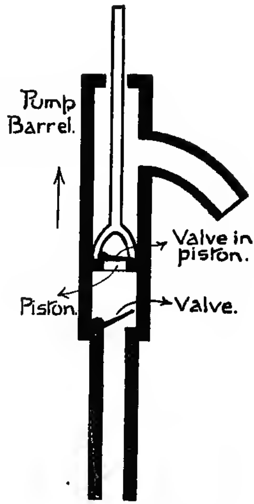
first lift pump was made, about 2,200 years ago, the ancients explained its action by saying that "Nature abhorred a vacuum." For if the water did not follow the piston up the tube, there would be an empty space below it, and an empty space is called a "vacuum." For more than 1,800 years after this, men were content with this explanation, though they found that the water would not follow the piston to a height of more than about thirty-four feet, and not even so far unless the piston was very well packed. So it was evident that Nature's objection to a vacuum had a limit and that it broke down when a column of this height had been lifted. The true explanation was given by Torricelli, the pupil of Galileo, to whom reference has been made. As his experiments will be described in the *Mastery of Air*, we shall do no more here than state that water is forced up the tube by the weight of the air that presses on the free surface of the water outside. At the sea-level, this amounts to nearly fifteen pounds on the square inch, and when the column of water exerts an equal pressure it can rise no higher.



A SYRINGE.

In a tube, such as has been described, the movement of the piston has to be as long as the tube, and this would be very inconvenient. The difficulty is overcome by providing a valve in the tube just below the lowest point reached by the piston, and another valve in the piston through which the water can pass in an upward direction only. A valve may be described as a gate or plug, which will open only in one direction. It is quite easy to see how water can be lifted with such a

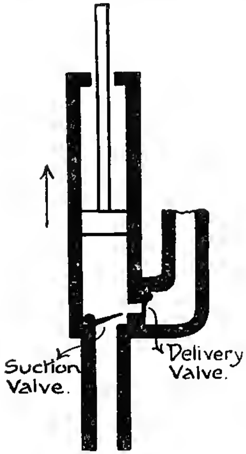
contrivance. With each upward stroke of the piston the pressure of the air in the barrel is diminished, and the air in the tube below it forces up the valve between them in order to escape. With the downward stroke the valve in the piston opens, and when the piston rises again the air which has passed through it is lifted up and escapes through the spout, while a fresh quantity of air enters the barrel through the lower valve. With each upward stroke of the piston the water rises in the lower tube, until it reaches the barrel, when it takes the same course as the air which has preceded it.



A LIFT PUMP.

The discovery which enabled an explanation of the lift pump to be given showed at once how water could be *forced* to a height greater than thirty-four feet. As shown in the illustration, the valve in the piston is done away with, and another valve is placed in a side tube leading from the lower part of the pump barrel. This valve opens with the downward stroke of the piston and allows the air or water in the barrel to pass into the side tube or lift pipe, closing again at the end of the stroke and so preventing its return. The height to which water can be lifted in this way is only limited by the force which can be applied in the downward stroke of the piston, and by the strength of the materials of which the pump is composed. It is useful to keep in mind the fact that a pressure of one pound on a square inch is produced by

a " head " of about two feet of water. In order to pump water up to a height of 100 feet, therefore, a pressure of at least fifty pounds on the square inch is required, and an allowance has to be made also for the friction of water in the pipes.




A FORCE PUMP.

If water has to pass from the pump through a considerable length of pipe, or be used in hydraulic machinery, there must be some means of equalising the pressure. Piston pumps are jerky in action, and, as water is incompressible, some elastic substance must be used to smooth out the jerks. For this purpose an air vessel is employed. The construction will be clear from the illustration. Air can be compressed into a very small volume, and so, when the pump expels water at the greatest rate and some enters the air-vessel, it squeezes the air there into a smaller volume. When the action of the pump is less vigorous, the elastic air expands and forces the water out into the pipes again. In this way excess of power at one part

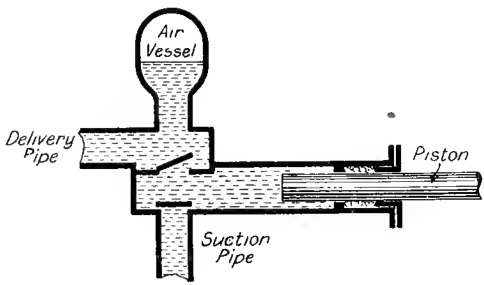
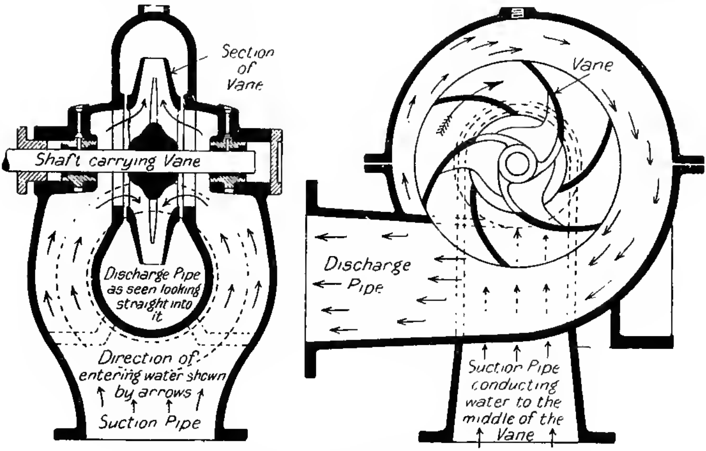



DIAGRAM SHOWING AN AIR VESSEL.

of the stroke is stored up and used again when the action of the pump is weaker.

There is another form of pump which has come into use since workshop processes have been so much improved that masses of metal can be whirled round at high speeds with safety. You know that if you swing a stone at the end of a string the string tends to break, and if the stone is liberated it flies off in a straight line, which is a tangent




SECTIONS OF A CENTRIFUGAL PUMP.

to the circle along which the stone was travelling. There is an old experiment with which, no doubt, you are familiar. A bucket full of water can be whirled round without any falling out, even when the bucket is actually upside down. The tendency for the water to fly outwards is so great that the force of gravitation is overcome, and the water exerts pressure on the sides and bottom of the bucket in whatever position it may be.

The force which is exerted by the rotating body is called

centrifugal force. If you can set up centrifugal force in water it is clear that you will be able to give it considerable velocity. A pump for performing that is called a centrifugal pump. It consists of a number of blades mounted on a boss, like the spokes of a wheel, only in this case there is no rim. The boss is mounted on an axle, and the whole wheel, or "impeller," runs inside a casing in which there is very little clearance except at the ends of the rotating blades. The water enters at the centre, is caught up and whirled round by the blades, and escapes through a pipe in the outer edge of the casing.

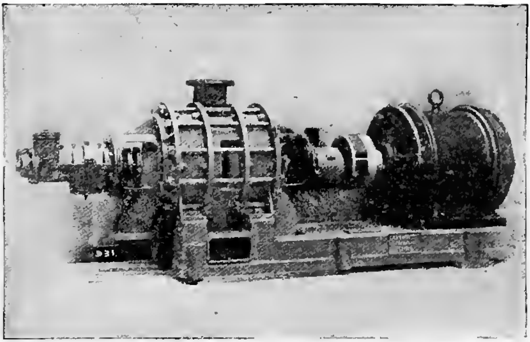
You can even obtain a high lift with these pumps by arranging for several wheels in succession to act upon the water; but a high speed is required. Suppose that ten gallons of water is whirled round at the speed of 300 revolutions per minute, and that the average distance of the water from the axis is two feet. The 300 revolutions per minute, therefore, are equivalent to about sixty-three feet per second. As a gallon of water weighs ten pounds, the total weight will be 100 lb. So from the formula which is given and demonstrated in books on mechanics, the force which the water exerts outwards is approximately—

$$\frac{100 \times 63 \times 63}{32 \times 2} = 6{,}200 \text{ lb.}$$

or nearly three tons.

One of the chief advantages of such a pump is that it has no valves, and it is, therefore, particularly useful for muddy water. When this is passed through an ordinary pump the fine particles either prevent the valves from closing properly, or cause wear by scouring the metal surfaces. In either case leakages are produced, and the pump is soon in need of repair.

All the contrivances we have described so far require to be worked by hand, or by a steam engine or electric motor; but there is one interesting form in which steam is used directly. In this case the steam engine and the pump are one and cannot be separated. There are no wheels or pistons, and the only things that move are the steam and the water. It is extremely simple in action, and the accompanying diagram will enable you to understand how it works.

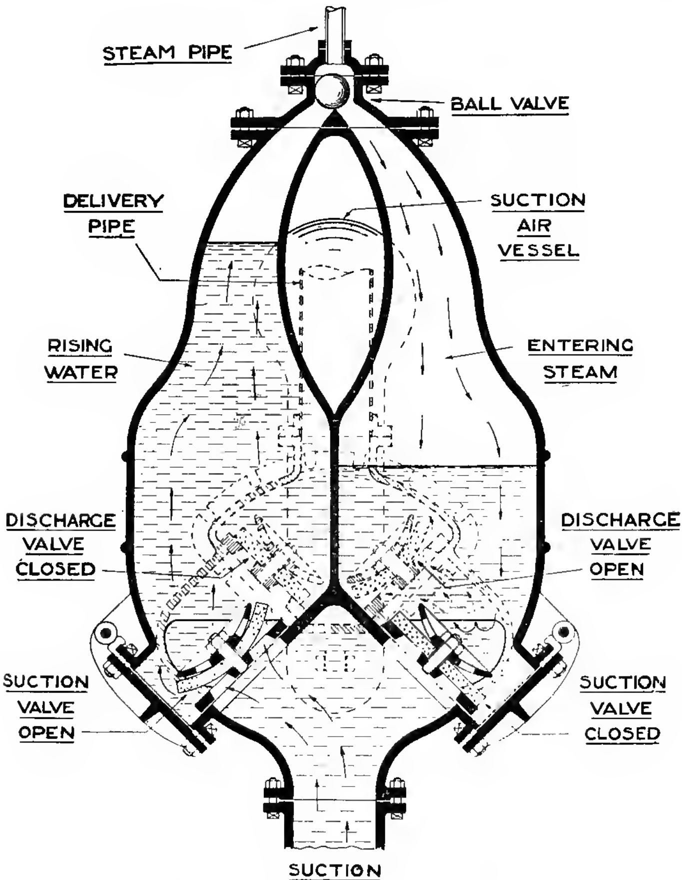


*By courtesy of Gwynnes, Ltd., Hammersmith.*

A CENTRIFUGAL PUMP.

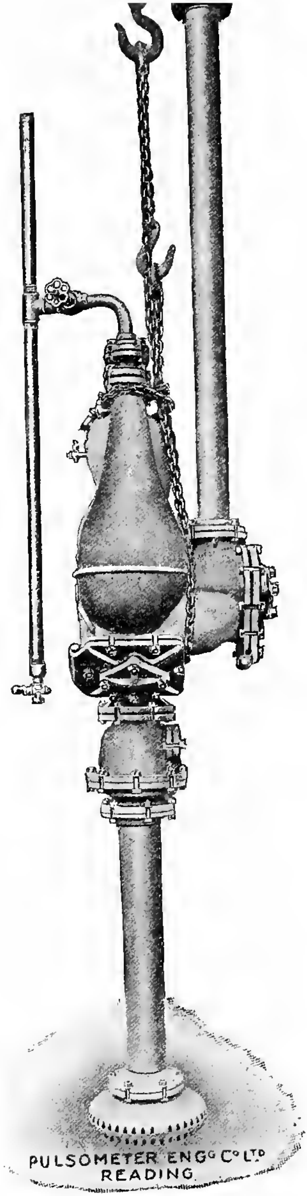
The pump consists of two pear-shaped vessels which communicate at the top with the same steam pipe. At this point is a ball valve, which, by rolling to one side or the other shuts off steam from one of the vessels. At the bottom are two valves, the lower one guarding the entrance to the suction pipe, and the higher one leading to the delivery pipe. Suppose, now, that both chambers are full of water and that steam is admitted into the top of the right-hand chamber, so forcing the water through the delivery valve. As the water is still, very little steam

condenses on the surface until the level falls below that of the delivery valve. At that moment the steam bubbles




SECTION OF A PULSOMETER PUMP.

through, some is condensed, the pressure falls, and the little ball at the top rolls over to the right. The only




*By courtesy of The Pulsometer Eng. Co., Ltd.*

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way the vacuum caused by the condensed steam can now be taken up is by the entry of water through the suction valve; in it comes with a rush and fills the chamber.

Meantime the steam has been forcing the water in the left-hand chamber through the delivery valve, and by the time the right-hand chamber is full again the left-hand is empty, except for the steam. As this begins to condense the ball at the top rolls over, and the whole process begins again. No foundation is required, and the Pulsometer Pump, as it is called, will work quite well suspended by a chain down the shaft of a mine.

Curious as is this steam pump, there is another method of raising water which is more remarkable still; for here the water actually lifts itself up without any assistance. If water is moving rapidly it exercises very little pressure, and force is only produced when the movement of the water is stopped. Velocity can, therefore, be converted into pressure, and pressure into velocity. Now, suppose water is flowing downhill in a pipe which has another pipe rising from it, but closed by a valve opening upwards at the bottom, as in the illustration. When the water reaches the dead end it will be stopped, the pressure will rise suddenly, and some water will escape through the valve. But this gives relief, so the valve closes again. The water which began to flow as soon as the valve

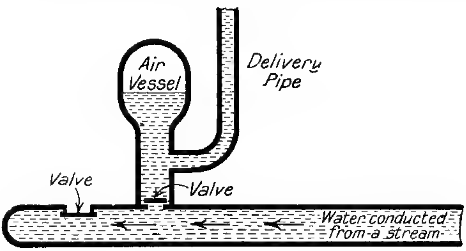



DIAGRAM OF A WATER RAM.

opened, is stopped as soon as it closes. The pressure, therefore, rises again, and more escapes through the valve. And so the changes from velocity to pressure and from pressure to velocity go on over and over again, and water is raised in a series of jerks to a height which is surprising. There is nothing to see and nothing to hear except the click, clack of the valve as it rises and falls with astonishing regularity. The water-ram is one of the simplest devices ever made by man, but it illustrates one of the most important principles in Mechanical Science.

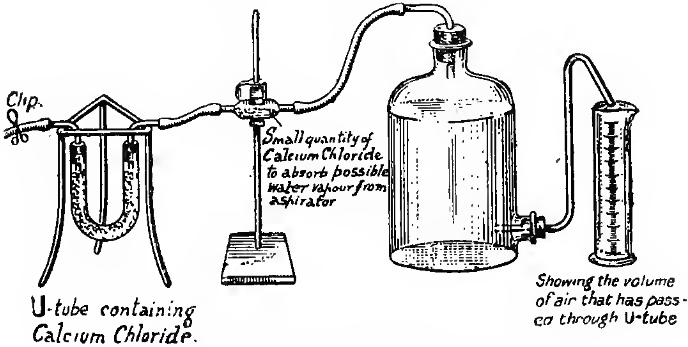
## CHAPTER VI.

### Impounding the River.

WHILE towns remained small, most of them could obtain the water, which was so necessary for health, cleanliness, and comfort, and for manufactures, from the springs or wells near by. But there is not, at any place on the earth's surface, an inexhaustible supply of the life-giving liquid, and a time soon comes when man has to go farther back, to the original source, and to catch the rain as it falls. When this need arises he looks to the mountains, to which the warm, moist winds give more generously than to the level plain.

Air can take up and hold as invisible vapour a quantity of water which varies with the temperature. In warm weather the air is nearly always moister than in cold. That is to say, if you were to collect a cubic foot of air in winter and in summer at the same place, and measure the amount of water which it contained, the latter would be found to contain the most. Such an experiment is not difficult to perform. Certain substances, like calcium

chloride, after being strongly heated to dry it, absorbs water very readily. If a bent tube, as shown in the figure, is filled with fragments of this material, and a measured volume of air is passed through it, the tube will extract the water and consequently increase in weight. As moist air is lighter than dry air, care must be taken to find the density (that is, the weight of unit volume) and from this to calculate the weight of air used.




AN EXPERIMENT TO MEASURE THE AMOUNT OF MOISTURE IN AIR.

When warm winds blow in from the sea they are heavily charged with moisture, and, if the land rises, they are compelled to curve upwards with it. In this way they enter a region of lower pressure; for, as is explained in the *Mastery of Air*, the pressure on a mountain is almost invariably lower than at the sea-level. Now, when the pressure on any portion of a gas is reduced, it expands and becomes cooler; thus the moist air can only retain a portion of the water vapour it contains. The excess is thrown out, and forms clouds, or, if the drops are large enough, mist or rain; or, if the temperature is low enough, snow or hail.

In a mountainous country, especially if it is not far from the sea, the summits are frequently wreathed in mist, and rain falls almost daily. Consequently, such districts are the wettest regions of the globe. How wet you will understand when you read that at Cherra Punji, in the Khasi Hills, in Assam, the fall is sometimes 600 inches a year! At Seathwaite, in Cumberland, there is a rainfall of about 140 inches, while the rainfall in the rest of England varies from twenty-four to sixty inches annually. If an inch of rain falling over an acre were to be collected and weighed, it would amount to more than 100 tons. An acre in the Khasi Hills would, therefore, receive more than 60,000 tons of rain per annum!

The water engineer, then, charged with the duty of satisfying an increasing need, turns to the mountains. He looks first for a suitable lake, or for a valley across which he can throw a big wall, or dam, and thus make a huge basin in which the excess of a rainy period can be stored against a dry one. Next, he has to arrange an aqueduct, or pipe line, through which the water can be conveyed over hill and dale to the town. And in both tasks he finds problems which are not the less difficult because they are as old as the profession to which he belongs.

As we shall have to speak pretty frequently about dams, it will be as well to consider at this stage how they are made. In the first place, they must be impervious to water, for none must pass out of the artificial lake except over properly made weirs, sills or spillways, or through sluices or small tunnels in the lower part of the dam; and these sluices must be provided with doors or gates which can be closed when necessary. Secondly, the dam must be so firmly anchored to the rock that it cannot slide down the valley—an example will be given later

in which an improperly anchored dam in Egypt did begin to slide downstream. Thirdly, the dam must be so wide at the base that it cannot be tipped over by the pressure of water behind it.

The simplest form of dam, the one that is always adopted where stone is scarce, is merely an earth embankment, with a core of clay to render it impervious to water. It has to be made with long sloping sides, the one to be submerged usually having a blanket of clay as an additional precaution. A very high earth embankment, therefore, takes up a large amount of the space for storage, and is not used to any great extent if the materials for a masonry or concrete dam are available. A masonry dam is a huge wall, wide at the base and tapering towards the top, with nearly all the slope on the down-stream side.

Whichever form is used, it must rest upon solid ground, and there is usually a vast amount of excavation to be done before any building begins. And then hundreds or thousands of workmen are engaged in putting thousands of tons of masonry in position. The work is sometimes delayed by frost, storm, and flood, for waterworks are built in some of the wildest and most desolate districts to be found within a hundred miles of civilisation. The men who construct waterworks have to "rough it" in temporary homes, with plenty of hard work and very few of the comforts of the town dweller, in whose service they labour. And they have to put into this labour the best they know, for the lives and health of thousands depend on them, and they build, not for a day or a month, but for ages to come and generations yet unborn.

Of all the great nations of antiquity the Romans have left the finest examples of waterworks. In England they did little more than make roads, but in Italy and Gaul they carried masonry and cement troughs for miles across

*Photo by* *Photochrome.*

THE RUINS OF A ROMAN AQUEDUCT.

country, and did not hesitate to drive tunnels when an awkward hill stood in their way. Such aqueducts are rare to-day, because pipes and reservoirs are so easy to construct. The Romans could only build open trenches, so they had only the alternatives of driving tunnels and of creeping round the mountain side, with the level falling steadily all the way. But now the use of strong iron or steel pipes enables the water to be carried up and down hill, in many cases with little or no pumping.

## CHAPTER VII.

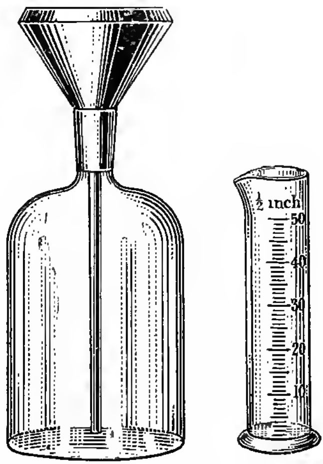
### Manchester Water.

MANY of you know Manchester, that black, smoky town in the south-east corner of Lancashire, which is famous all over the world for its manufactures, its clever workmen, and its blunt, hard-headed business men. And those who know it will realise that it requires a great deal of water. This need was felt very early in the nineteenth century, for the steam engine had enormously increased the output of cotton goods, and Manchester was the centre of the trade. The population of the twin towns of Manchester and Salford in 1842 was 300,000—twice as great as that of London two hundred years before. Water was obtained from wells sunk into the red sandstone, and from the river Medlock, from which it was pumped into a reservoir at Gorton.

In 1844, the Corporation called in Mr. J. F. Bateman as Consulting Engineer, and, after some difficulty, obtained powers from Parliament to proceed with a scheme. Mr. Bateman's idea was to get water from the western slopes of the Pennine Chain, and he ultimately selected the Longdendale Valley for the purpose. He thought that he could obtain a sufficient quantity of

water by constructing a dam across the mouth of this valley.

Two main difficulties had to be faced in the early stages. One was the opposition of the mill-owners, who used the water for driving their machinery, and in dyeing and bleaching their goods. They were not easily convinced that the storage of water in a large reservoir would give them the amount which they had been accustomed to use in a year, though the supply might be more regular. The other difficulty was that of estimating the rainfall. Rain-gauges for measuring this were used at that time by only a few scientific men, and there was no systematic record such as is now, and has been for many years, conducted by skilled observers acting under the direction of the British Rainfall Organisation.



A RAIN-GAUGE.

A rain-gauge is composed of a basin or funnel with a sharp edge, having a definite area. It is placed in an exposed position, and the water which falls upon it is measured in the graduated glass vessel. The standard gauge has an opening of eight inches in diameter, though for many purposes one of four inches gives results which are sufficiently accurate. As the rainfall at any place varies a great deal from year to year, measurements are necessary over a long period of time, and the early water engineers were at a great disadvantage. Mr.

Bateman fully recognised the importance of this, and was busily occupied in collecting information between 1844 and 1848, when at last he was able to begin operations.

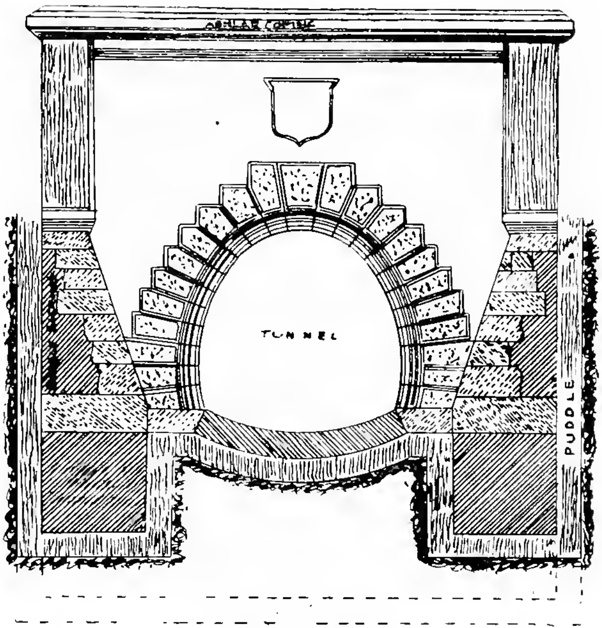
About the building of the dams very little need be said, though the work was not accomplished without exciting incidents. It was necessary to divert the course of one of the streams for a time, and, when some progress had been made, a flood occurred. Measurements of a previous flood in the district—the worst that had ever been known—had indicated that a flow of about 2,000 cubic feet per second was the greatest that might be expected, and the cut was made large enough to carry 1,500 cubic feet in that time. But one day the water came down with a rush and a roar, overflowed the cut, broke through the partly finished dam, and swept in a destructive torrent over the low-lying land. It was calculated that at its height the flow amounted to 4,000 cubic feet a second.

At ordinary times the water was quite clear, but after heavy rain it was coloured dark brown with material which it had brought from the peaty uplands, and it had to stand for some time in a reservoir to settle before use. An ingenious attempt was made to separate the clear and muddy water, so that the former could be passed on to be used directly. A narrow slot was cut in the spillway over which the water flowed. In dry weather the slow stream fell through this into a channel below, but in wet weather the water jumped right over it and was carried to a settling reservoir.

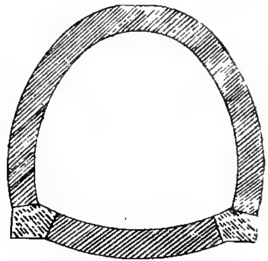
From the Longdendale Valley the water was carried to the Godley Reservoir, passing on its way through the Mottram Tunnel. This tunnel is six feet in diameter and 3,100 yards long, and is capable of passing 50,000,000

# Manchester Corporation Water Works
## Section of Mottram Tunnel

ELEVATION




TRANSVERSE SECTION OF TUNNEL.

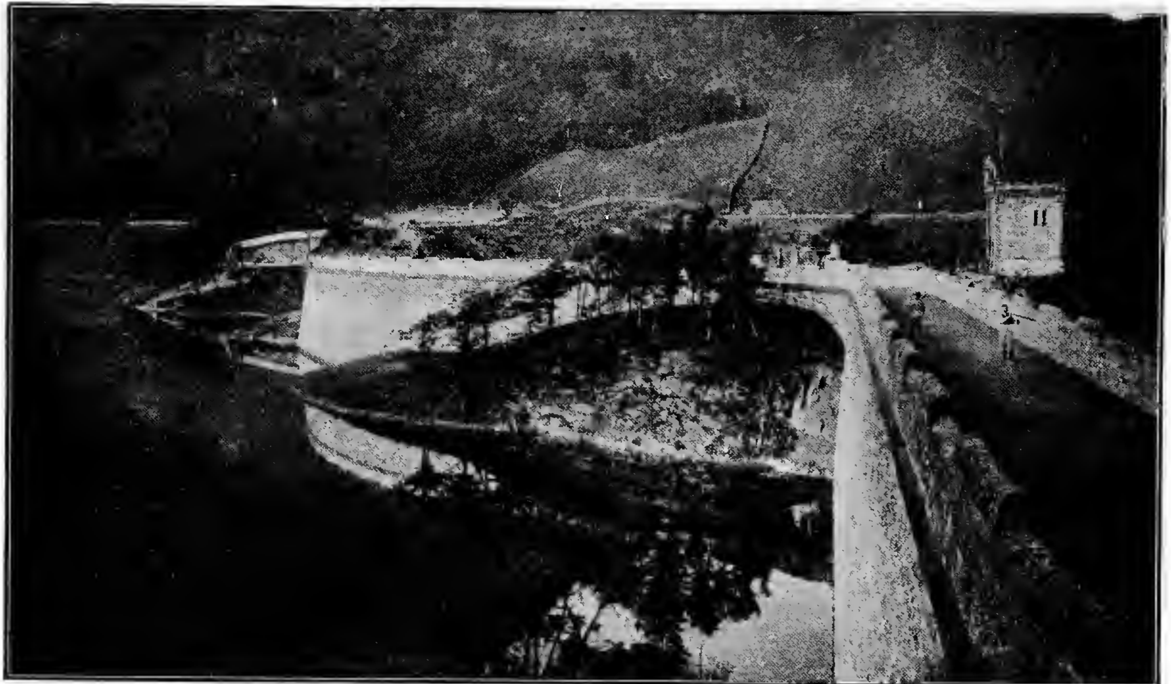


gallons of water a day. It is lined with masonry nine inches thick. Trial borings showed the presence of a quicksand eighty feet below the surface and 700 yards wide. As you know, a quicksand is a bed of sand saturated with water, and it was felt to be necessary to drain this before attempting to drive the tunnel. Ten shafts were sunk, and 2,000,000 gallons of water a day were pumped out for many months.

During the progress of the work an accident occurred. Two of the engineering inspectors were being lowered by means of a bucket, down a shaft 205 feet deep, and the engineman had started them too fast. They shouted to him to go slowly, and he stopped the engine so abruptly that the teeth of the cogwheels in the winding gear stripped, and the two engineers fell to the bottom. All shafts are sunk lower than is actually necessary to allow of a well, or *sump*, at the bottom for drainage. The sump in this case was covered with three-inch planks, through which tub and men crashed; the result was serious, though, fortunately, the men's injuries were not fatal.

The water leaves Godley Reservoir through iron pipes forty inches in diameter, and Gorton Reservoir through similar pipes thirty-six inches in diameter. The pipes were connected by what is known as "socket" joints; they are one of the earliest examples of pipes cast according to what is still the regular method where great strength is necessary. They are cast vertically with the socket end downwards, because the lower portion of a casting, which solidifies under the weight of the upper layer, is always the soundest.

Great care had to be taken in designing the valves in order to prevent them from being closed too quickly. When a column of water thirty-six or forty inches in diameter and several miles long is moving rapidly, an



*By courtesy of* *The Manchester Corporation Water Works.*

EMBANKMENT AND VALVE HOUSE, THIRLMERE.

enormous force is required to stop it. If an attempt were made to do this too suddenly the pipes would burst. Whatever the reason, a burst in such a pipe would be a very serious matter; it would cause a great deal of damage, and, once started, would be difficult to stop except at or near the reservoirs. To meet this, automatic, or self-closing, valves were designed by Mr. (afterwards Lord) Armstrong. A vane fixed to a spindle which passed through to the outside hung inside the pipe, and was connected by a crank and levers to a valve. So long as the water flowed through the pipe with its ordinary velocity, the vane was unaffected; but if the velocity increased to the extent it would increase to in the case of a burst, the vane was forced to one side, and the valve, operated by a falling weight, was slowly closed. The arrangement was put to a practical test, as soon as the service was established, by the bursting of a main in the town of Hyde, and it worked admirably.

With the various additions and improvements which were made from time to time, the works at Longdendale supplied Manchester for many years with about 24,000,000 gallons of water per day, and still allowed 14,000,000 gallons to flow through the water-courses across the valleys of which the dams had been thrown. But it was found that even this quantity was not sufficient for the vast increase in population that was taking place, and by 1870—within twenty years of the water being turned into the pipes—a new scheme was being considered.

And now Manchester people made up their minds to launch out boldly, and to do what no town had ever done before. The towns were growing so thickly all round them that they were determined to go a long way off, where pure water could be obtained without fear of pollution for many generations to come. The chosen

*By courtesy of* *The Manchester Corporation Water Works.*

MANCHESTER WATER CROSSING THE RIVER LUNE.

source was Thirlmere, the lake which lies at the foot of "The mighty Helvellyn," 535 feet above sea-level, in one of the rainiest places in the country. In spite of opposition from landowners, who demanded heavy compensation, and from persons who apparently preferred to see a great city smitten with fire and pestilence rather than that a single beauty-spot should be marred, they proceeded with the scheme in 1879, and got their Bill passed at the second attempt.

The area drained by Thirlmere is about 11,000 acres, and the lake itself covers 335 acres. It is about three miles long by one-quarter mile wide, and the water escaped through a narrow opening at the northern end which could easily be closed by a dam. A dam was accordingly built of masonry and concrete, of such a height that the level of the lake could be raised by fifty feet. It was calculated that a supply of 50,000,000 gallons per day could be obtained by this means.

The distance the water had to be conveyed was nearly ninety-six miles—more than twenty miles farther than any other town supply in England before or since. For more than thirteen miles it flows through tunnels, the first of which, under Dunmail Raise, took four years to construct. A concrete conduit, or covered channel, carries it for thirty-seven miles, and for forty-five miles it flows through cast-iron pipes varying from forty-eight to thirty-six inches in diameter. There are no less than thirty-three bridges, those over the Ribble, Lune, Troutbeck, and Irwell being handsome three-span structures, and there are ten subways. Fifteen years after the Act was passed the water flowed into the city, and the inhabitants were again relieved from the burden of anxiety. All honour to the men who fought for it and carried it through!

# CHAPTER VIII.

## The Thirst of Liverpool.

WHEN Manchester was worrying about its water supply, Liverpool was in a similar plight. All the available fresh water was obtained from wells. Two companies entered into the business in earnest, and at one time laid their pipes side by side in the same streets in the hope of securing one another's customers. This foolish plan was soon given up, and the city was divided into areas, each served by one company.

Liverpool was then, as now, the great cotton port, and the same causes which led to Manchester's growth were increasing her population also. The lack of water became serious. It was only turned on for a few hours a day; some people fought for it or stole it, and many went without. Disease broke out from time to time; and disastrous fires occurred, which needed thousands of gallons to quench them.

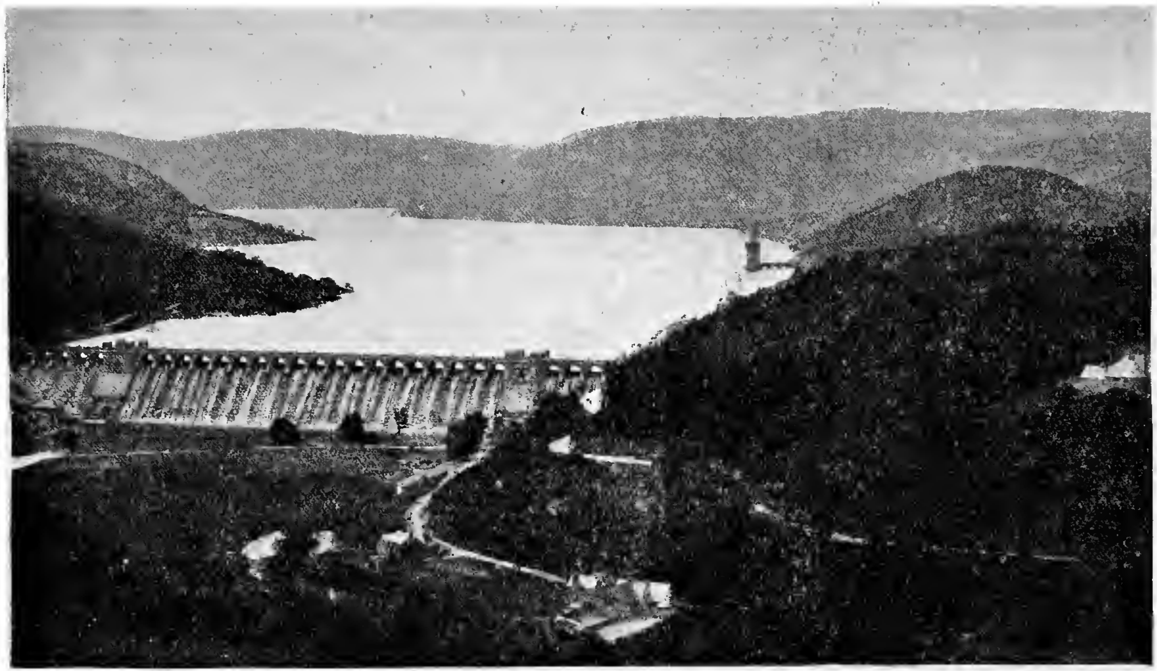
The usual dispute arose as to whether more wells should be sunk or water brought from the hills. The difficulty of coming to a decision was greater here than in the case of Manchester, because the city was bounded on the west by the sea, and on the south by the river Mersey, while the country north and east was dotted over with growing manufacturing towns. Manchester, on the other hand, was fairly close to the sparsely populated western slopes of the great central mountain chain of England. The opinion of the engineers was that the necessary supply could not be obtained from the wells, so in 1847 the Council obtained an Act of Parliament authorising them to bring their water from Rivington, the high ground between Bolton and Blackburn. The

construction of the Rivington reservoirs, therefore, was started in 1852, and in 1857 the new water flowed into the city.

The gathering-ground consists of 9,873 acres, lying at from 450 to 1,500 feet above sea-level. There are four principal streams, and these were held up by earthen embankments thrown across their valleys. Altogether there are eight reservoirs, covering 598 acres, making a huge lake five and a half miles long, and holding 4,105,000,000 gallons. The highest embankment is across the Yarrow. It is 130 feet high from the bottom of the valley, and in one place the puddled clay core had to be carried down for 167 feet, so that at this point the total height is no less than 297 feet.

The overflow is just under 379 feet above sea-level, and the water flows partly through cast-iron pipes, forty-four inches in diameter, and partly through a tunnel to Aspull Reservoir three miles away. The tunnel is 1,476 yards long, partly oval and partly circular in section, five feet in diameter, and lined with brick. The circular portion of the tunnel is built where it lies nearer the surface. From Aspull the water passes through eight miles of pipes to Montrey House Reservoir, near Garswood; from Montrey House through six-and-a-quarter miles of pipes to Prescot; and from Prescot through two lines of pipes, forty-four inches and thirty-six inches respectively in diameter, to Kensington. There are screw-down and automatic valves at various points in the line, so that the water can be cut off during repairs or in case of accident.

Extraordinary care has been taken to prevent pollution. Gradually the Corporation have bought up as much of the property on the land from which the water drains as they have been able to secure; and the buildings and



*By courtesy of* *The Liverpool Corporation Water Works.*

LAKE VYRNWY.

mills have been regularly inspected. In many cases alterations have been made and new sanitary arrangements put in at the cost of the Council. Few who use the water of any town realise the amount of thought and care which has been spent upon the supply.

It was soon found that even the rain which ran off nearly 10,000 Lancashire acres would only serve for a time, and within twenty years the opinion of engineers was taken on the question of obtaining a further supply. Two proposals were made: one, to bring the water from Haweswater in Cumberland; and the other, to dam up the valley of the Vyrnwy, one of the tributaries of the Severn that lie hidden among the mountains of North Wales. The second found favour and was sanctioned by an Act passed in 1880.

For the next eight years a small army of men were busy with pickaxe and shovel. The little village of Llanwddyn, consisting of some forty cottages, a church, two or three chapels, and a school, stood upon ground that was soon to become the bottom of a lake. The buildings were pulled down, and the land which was to be submerged was cleared of everything that could cause pollution. A few miles away a huge quarry was hewn out of the hillside to provide stone for the dam; but all the other material had to be carted ten miles over rough mountain roads from the nearest station on the Cambrian Railway.

In 1888 the water was allowed to collect, and before the end of 1889 the lake was full. Two years later the first supply reached Liverpool. But the work was not yet completed—in fact, it has been going on more or less ever since. Included in the area purchased by the Council were two other valleys—those of the Marchnant and the Cowny, and these rivers have been conducted

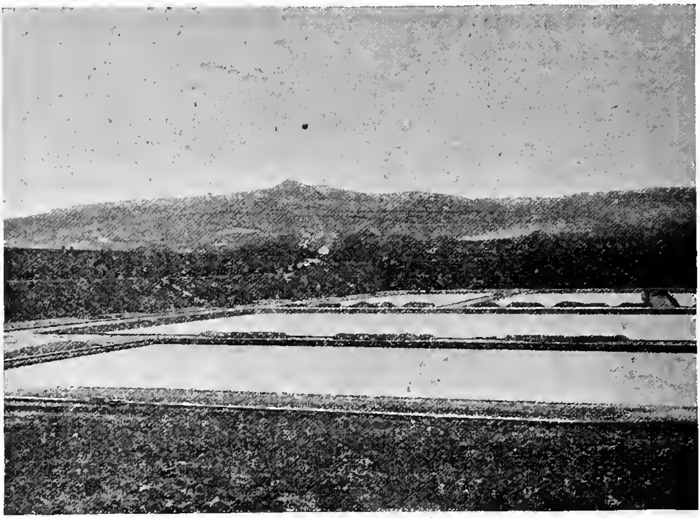
directly into the lake by tunnels, one and three-eighths and one and a quarter miles in length respectively.

Let us look now at the dam itself. It is a tall, massive wall of masonry stretching 1,172 feet from rock to rock. From the old river bed up to the overflow is eighty-four feet, but, as in some places the foundations had to be carried down sixty feet, the total height to the sill is 144 feet. The thickness at the base is 127 feet, tapering to about twenty-one feet at the top. Above the sill, over which the surplus water flows, is a roadway, supported on elliptical arches, seventeen feet above the level of the lake when full. No less than 220,000 cubic yards of earth had to be excavated. The dam itself contains 260,000 cubic yards, and weighs 510,000 tons.

The area from which water is collected is more than 2,200 acres. The lake, four and three-quarter miles long, and about half a mile wide, contains 1,115 acres and holds 12,131,000,000 gallons, or about three times as much as the Rivington reservoirs.

Now follow the course of a drop of water as it leaves the lake on its journey to Liverpool. First it creeps through fine copper gauze into a steel pipe thirty-six inches in diameter, then through a four-foot concrete culvert until it reaches the Hirnant Mountain. Here it enters a tunnel seven feet in diameter, emerging on the other side of the mountain after a journey of two and a half miles underground. From Hirnant it travels through the usual forty-four inch cast-iron pipes to Parc Uchaf Reservoir, and then on to Oswestry through another seven and a quarter miles of pipes and one and three-quarter miles of tunnel. At Llanforda, near Oswestry, is a reservoir capable of holding 46,000,000 gallons, together with large filter beds containing two feet of sand on top of twelve inches of gravel. After soaking through

these it runs for seventeen and three-quarter miles to Malpas, then eleven and a half miles to Cotebrook, resting for a time at each place in a reservoir. From Cotebrook to Norton is eleven miles, and here the ground is not high enough for a reservoir, so the water is taken up into a high tank for another rest. Then,



*By courtesy of* *The Liverpool Corporation Water Works.*

FILTER BEDS AT RIVINGTON.

with a rush, it sets off for the Mersey, dives underneath the Ship Canal and the river in turn by means of a twelve-foot tunnel, and reaches the great storage reservoirs at Prescot after a journey of sixty-eight miles.

All the way from source to destination the water is under strict control. There are stop cocks every two and a half miles, and eleven automatic valves. There are measuring instruments to record the flow, and telephones

and bell signals connecting every station with the Water Engineer's Office in Liverpool. Though hidden inside pipes or beneath mountains and rivers, the slightest tendency to break bounds is recorded and the signals flashed along the line to bring it under subjection at every point. Two and a half miles may escape, but what is that against sixty-eight miles in the pipes and the millions of gallons in the reservoirs and lakes ?

We have so far spoken of a single pipe ; but there are three side by side. The first was laid down in 1891 ; the second in 1902 ; the third is now being put into service. The Council are compelled by their Acts to supply other areas in their immediate neighbourhood, and even so far away as Chorley, because their demand on the Rivington area interferes with the supply to that town. Moreover, any place within twenty miles of the triple pipe line from the Welsh hills is entitled to purchase a drink, and the Borough of Wallasey takes advantage of this privilege. But Liverpool must not encroach upon an area to the east of her pipe lines and reservoirs, which has been given to Manchester, or she will get into serious trouble. The various sources of supply controlled by the city serve areas amounting to 215 square miles and the needs of a population of more than a million persons. So it is a great scheme, worthy of the great city which promoted it.

But wait until you have heard about New York.

## CHAPTER IX.

## New York and its Water Supply.

It is very interesting to notice that a number of towns in different countries began to require a large supply of

water at the same time, and to look back to the primary cause. James Watt made the steam engine a workable machine in 1769. It was first used for pumping and haulage in mines; then its employment was extended to the textile and other industries; and in the first thirty years of the nineteenth century it was applied to the railway and the steamship. At once commerce began to grow, and the big towns rapidly to increase in population; consequently, between 1840 and 1850, Manchester, Liverpool, New York, and many other towns entered upon the first of their great water schemes, which, before 1880, were again found to be insufficient to meet the growing demand.

America has, or had in the early days, an advantage over an old-established country like Great Britain. There were fewer people who could claim to own the land and water and, therefore, demand enormous sums of money as compensation for encroachments upon, or interference with, their privileges. British canals, British railways, British waterworks—all cost a great deal more money than they should have done, because landowners and others had to be bribed before a Bill could be passed through the House of Commons.

The first step taken by the city of New York was to impound the waters of the Croton River, a tributary of the Hudson, in 1843. A lake holding 2,000,000 gallons was thus made, and several of the smaller streams running into the Croton were also dammed at a later date. But, before 1880, more water was needed, and a larger dam nearer the Hudson was decided on. This was, until recently, the largest in the world. Stretching for 1,200 feet from bank to bank, it is 300 feet high from the foundations, and 216 feet wide at the base. The usual difficulty was found in rotten rock in the bed of

the valley to say nothing of caves twenty or thirty feet long, and large enough for two or three men to walk through abreast. No less than 1,500,000 cubic yards of excavation had to be made, and the dam itself contains 833,000 cubic yards of masonry.

The caves were filled up with rubble and concrete. Springs were fitted with three-inch pipes firmly cemented in place, and then liquid cement was forced in under pressure. The surface of the rock upon which the dam was to be made was scraped and washed, and then painted with liquid cement so as to afford a "hold" for the masonry blocks which were to be laid upon it. In frosty weather the sand for the cement was heated by steam pipes, the stones were warmed by blowing steam upon them, and at night the masonry was protected by matting.

But, before any excavation could be undertaken, the river had to be diverted from its bed and sent through an artificial channel cut in the right bank. A wall was built across this in the form of an archway, through which the surplus and compensation water could escape downstream. The land which was to be submerged had to be cleared. Three villages were pulled down, as well as many isolated homesteads. Cemeteries had to be transferred, and roads, railways, and telegraph lines diverted, to make room for the vast lake, nineteen and three-quarter miles long, which was to be formed. When the dam was closed and the water was allowed to collect, the work had occupied nearly a thousand men for fifteen years, and had cost the citizens £1,500,000.

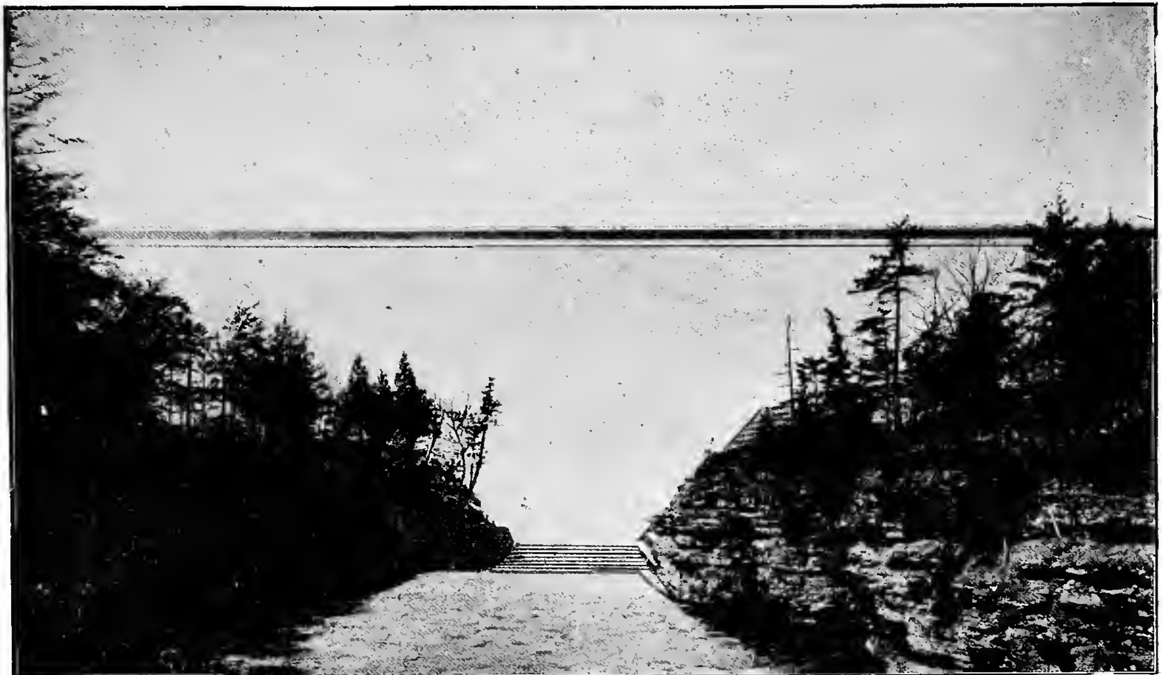
Meantime a great aqueduct had been built to convey the water to New York, over thirty-three miles away. You have heard how tunnels were needed in the Manchester and Liverpool schemes, but they form less than

a sixth of the total distance. In this case no less than twenty-nine and three-quarters of the thirty-three and a quarter miles were driven through the mountain and under the river. For about two and a third miles there are eight rows of forty-eight inch pipes, and for less than two miles the water is in open channels or "cut and cover." At the Harlem River the water drops down a shaft 174 feet deep, then runs through a tunnel 1,300 feet long, and rises in a shaft on the other side, whence it flows into the reservoir in Jerome Park.

There are longer aqueducts in Great Britain, but none so large or capable of passing such an enormous volume of water. The tunnels are more than twelve feet in diameter, and 300,000,000 gallons per day can flow through them. The cost of the aqueduct alone was nearly £4,000,000, which brought the total cost of the Croton water supply up to £5,500,000.

Invigorated by this plentiful stream of water, New York continued to grow like a cabbage. The population increased by leaps and bounds, so that, by 1905, it was seen that not 300,000,000, but 1,000,000,000 gallons would ultimately be required. This time it could not be had so close at hand, and the engineers had to go more than eighty miles away to find a suitable collecting ground. Their choice fell upon the Catskill Mountains, which lie in a N.N.W. direction from the city. Here a tract, 900 square miles in area, which is drained by four rivers—the Catskill, Rondout, Esopus, and Schoharie—is estimated to provide 600,000,000,000 gallons per day all the year round.

A beginning was made by damming the valley of the Esopus at a place called Olive Bridge. The embankment is partly earth and partly masonry, with a total length of 5,000 feet and a height of 220 feet. The middle section,



*By courtesy of the* *New York Water Board.*

FACING THE OLIVE BRIDGE DAM, ASHOKAN RESERVOIR, U.S.A.

1,000 ft. in length, is of masonry, of which it contains 1,000,000 tons. This is continued towards each side of the valley by huge walls of earth having a volume of 6,000,000 cubic yards. Behind this is a lake twelve miles long and two miles wide, holding 120,000,000 gallons.

The water is conveyed to New York by an aqueduct which puts all the others in the shade. It is not so long as that which brings water from Thirlmere to Manchester, but it is capable of carrying twelve times as much water. Imagine a diameter of seventeen feet—nearly as large as an ordinary railway tunnel, and half as large again as one of the London Tubes! Rivers and mountains lie across the path it has to take. To get under the rivers, three times does it drop down a vertical shaft, run for several miles underground, and then rise in another shaft. In one instance a shaft is 480 feet deep, in another, 750 feet, and in a third, nearly 1,000 feet; and in two of these the underground run is four and a half miles. You will easily realise that this is one of the most stupendous engineering feats of the world.

## CHAPTER X.

### The Coolgardie Pipe Line.

If you look at a map of Australia, you will see that the continent consists in the main of uninhabited desert. With the exception of a patch of land in the S.E. corner, the continent has an encircling barrier of hills not far from the coast-line. As the moist winds from the ocean rise over the summits of this barrier, they deposit the greater portion of the water they contain, and a narrow strip on each side of the mountain chain receives sufficient

*By courtesy of the* *New York Water Board.*

RONDOUT PRESSURE TUNNEL, CATSKILL AQUEDUCT.

water to grow wheat and other cereals. But so small is the rainfall and so scarce the water in the interior of the continent, that no part of the British Empire has been so imperfectly explored. Few of the daring, intrepid men who have penetrated this arid waste have lived to tell the tale.

But there is one thing that will lead men to face any danger, and that is gold. The thirst for gold is greater —at first—than the thirst for water. So, when gold was discovered at Coolgardie in 1892, there was a rush of desperate men, heedless of warning, reckless of danger, to the new Eldorado. Gold there was in plenty; but water there was not. When they were 360 miles from Fremantle, on the coast of Western Australia, the treasure-seekers had passed over the mountain belt into a region where the rainfall is only about seven inches a year, and where a few feeble streams trickle down the mountain gullies, and lose themselves in the parched soil of the tableland. Water was needed for washing the gravel in which the grains of yellow metal lay hidden; water was wanted for health, cleanliness—nay, for life itself. Food was needed badly, and machinery, too, for working the mines. So, with infinite labour, a railway was driven from the coast, and something was done to render life possible in this wild and inhospitable region.

Every step was taken to store up what water there was and to obtain more. Dams were made, tanks were erected, wells—3,000 feet deep—were sunk through solid granite. But all to little purpose. The price of the precious liquid went up to 2s. 6d. a gallon. The water required by the thirsty locomotives which toiled over the rugged slopes cost £1,000 a day! And all the efforts of the Australian Government could do no more than reduce the cost to about £4 for a thousand gallons.

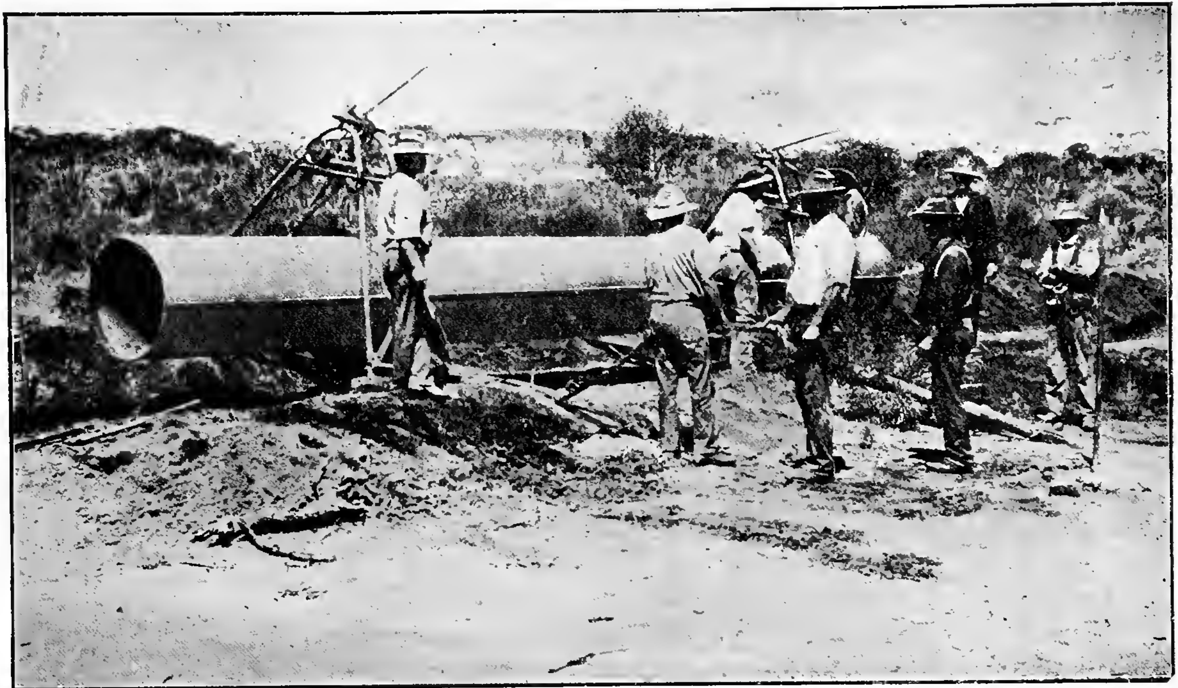
*By courtesy of* *Messrs. James Simpson & Co., Ltd.*

THE HELENA WEIR.

When Sir John Forrest visited the district in 1895 he decided that water must be brought to the population which was so sorely in need of it. But from where? From the point at which the railway leaves the coastal plain there was no spot showing signs of any supply such as was necessary—except one. About twenty-three miles from Fremantle, the river Helena emerges from the hills between rocky cliffs and flows swiftly towards the western sea. To dam this river and pump the water for 350 miles over mountains which tower nearly 1,600 feet above sea-level was a big task, but it was possible; and in 1896 Sir John Forrest introduced a Bill into the Legislative Assembly to authorise the work. Two years later the Bill became an Act, and the problem was tackled in earnest.

The dam is of concrete, with its foundations in some places 100 feet below the bed of the river, and at no part of its base is it less than eighty-five feet in thickness. It forms one end of a reservoir, which holds 4,600,000,000 gallons of water. From this reservoir, which is 340 feet above sea-level, the water is pumped to another reservoir 415 feet higher, and again to one 1,095 feet in elevation, and still it has covered less than twenty-four miles of its journey. Next it flows in pipes buried deep in the ground, down a steep slope, to a depth of 300 ft., then over undulating ground and up again to a point only ninety-five feet lower than that from which it started on its more independent course. The distance it has now covered is thirty-six miles. It again flows in pipes downhill, and then up again until a point is reached 728 feet above sea-level and seventy-seven miles from the dam.

Pumping then begins again. The first stage carries the water to a height of 980 feet, 140 miles from the dam; the next, 172 miles (or nearly half-way), and 1,293 feet;



*By courtesy of* *Messrs. James Simpson & Co., Ltd.*

LOWERING PIPE INTO TRENCH.

and four more pumping stations carry it to the total distances of 218, 250, 295, and 307 miles, and to the total heights of 1,326, 1,411, 1,447 and 1,585 feet respectively. Here it is at the highest point in its course, and thence it flows by gravity to Coolgardie, to Kalgoorlie, twenty-three miles further on, and to other towns in the neighbourhood.

The pipes are of iron, thirty inches in diameter and a quarter of an inch thick. They are twenty-eight feet lengths, each weighing nearly one and a half tons, and some 60,000 were required to complete the line. They are buried below the surface of the ground in order to protect them from changes of temperature. The water is pumped through them by twenty Worthington pumps, at the rate of 5,000,000 gallons per day. If the average velocity of water in the pipes is two feet per second, find how long it would take a drop of water to travel from the Helena Dam to Coolgardie. The result will be interesting and worth thinking about.

Perhaps you would like to know what this cost, and in any case you will not be surprised to hear that the cost exceeded the estimate. The original notion was that it could be done for £2,500,000; but it actually came to £3,252,700, the pipes alone costing over a million. Moreover, the working expenses came to over £70,000 a year. But in 1910 it supplied more than 1,000,000,000 gallons of pure water, at less than 10s. a thousand gallons, to twenty-six towns, the inhabitants of which needed it so badly that they paid nearly £240,000 for it. So, after all, the Government gets about five per cent. on its capital, and that is a business arrangement.

And now we shall leave questions of water supply, and see in what other ways man has found out how to utilise the liquid which occasionally gives him so much

trouble. Even this little survey has led to some travelling. You have visited in imagination London, Manchester, and Liverpool. Then, in the same airy way, you have crossed the Atlantic to marvel at the energy of the citizens of New York; and, finally, you have gone to the other side of the world, and have seen how the pioneers on the edge of civilisation have been enabled to overcome the obstacles that Nature has thrown before them. The remaining chapters will take you just as far afield.

# SECTION III

## RECLAIMING THE DESERTS.

### CHAPTER XI.

### Storing the Waters.

MOST of the readers of this book live in countries where fields and gardens are watered by the rain which falls plentifully throughout the year. Except for the watering-can or hose in gardens, on lawns, and on cricket pitches, there is no need to supply water artificially. Dry periods there may be, when growing crops suffer a great deal; but we complain more frequently of periods of excessive wetness, when potatoes and corn are ruined. So most of us hear only of great irrigation schemes through the newspapers, or read about them in books and magazines that chance to fall into our hands.

Let us consider for a moment what sort of conditions render an artificial supply of water necessary for farming. It is evidently needed to fight against drought, and drought arises from absence of rain. In India, the south-west monsoon, or wet wind from the Indian Ocean, blows from April to October, and the north-east monsoon, a dry wind, blows between October and April. There is consequently a very dry period, some parts being practically rainless. In Egypt rain hardly ever falls, but once a year the River Nile brings down vast quantities of melted snow from the mountains of Abyssinia, and between July and November the valley is covered with muddy waters. When the level falls the mud is left

behind in a thick fertile layer in which all kinds of crops can be grown.

But these are not the only dry places in the world, even if we leave out of account great desert regions like the Sahara. There are arid and inhospitable stretches of land in the Western United States, which, if they are supplied with water, will grow all kinds of grain and

*By courtesy of* *Photopress.*

NATIVES DRAWING WATER IN EGYPT.

fruit ; and even Canada has districts under the lee of the Rocky Mountains which, under natural conditions, receive less rain than is necessary to render them useful. With the exception, perhaps, of Western Canada, all these regions supported large populations in past ages ; even the desolate wastes and barren rock of Arizona contain traces of a civilisation which has now disappeared.

It has been left for the British and American nations to carry through the greatest water schemes in the

world. The area won from the desert in British India alone is 36,000,000 acres ; in the United States 13,000,000 acres ; and in Egypt more than 6,000,000 acres. There are 640 acres in a square mile, so these areas amount to nearly 100,000 square miles, or a strip 1,000 miles long and 100 miles wide. Imagine the corn that can be grown on this, the raw cotton it will produce, the cattle and sheep it will support, and say whether it was not worth doing.

And that raises an interesting question. How was it done ? Why, by storing up the water when it was plentiful and distributing it again when the sun poured its rays pitilessly on a dry and thirsty land. Let us take Egypt as an example. Here is the country in which one of the oldest civilisations in the world flourished, the country in which some of the earliest fields were tilled and the earliest crops grown ; the country in which some of the earliest efforts of man to control the water were made.

The ancient Egyptians soon learned that the Nile flood was not to be depended on ; for, so level is a large portion of the valley that a few inches' difference in the rise of the river made all the difference between famine and plenty. Still, it was their skill and foresight that enabled them to stay by their homes and possessions when other races of men were forced to seek a land in which food was more plentiful. When famine was rife in Palestine, Joseph's brethren were sent thither to procure food, for "there was corn in Egypt." Even in those days the Egyptians cut canals, and when the water was low they let down a bucket into the stream at the end of a long springy pole, and as this sprang up it emptied itself into a trough leading to the canal. Another method of raising the water from the river was to turn a wheel with an endless rope having large earthenware jars or buckets fitted on the rim.

This was mounted so that they dipped into the water, and, as they turned over, poured out their contents into a trough. This bucket wheel had another wheel, with pegs serving as cogs, at the other end of the axle ; this was turned by a similar wheel on a vertical axis, worked by an ox.

MEHEMET ALI.

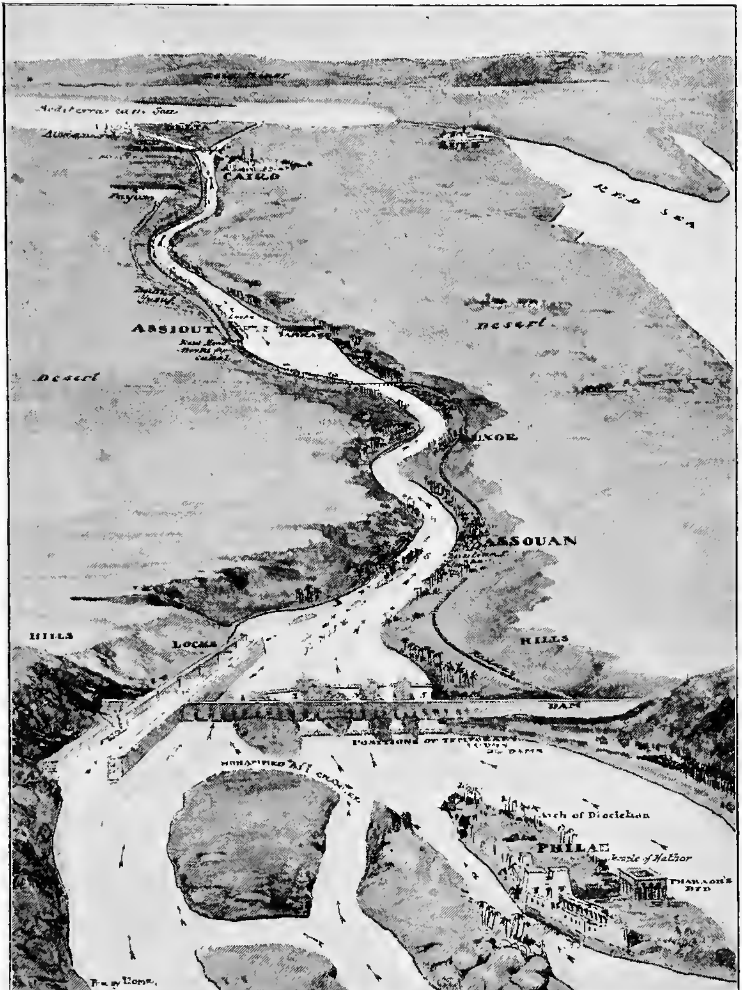
The first modern proposal for a big irrigation scheme came from the great Napoleon and was put into operation in 1837 by Mehemet Ali. It involved the cutting of an enormous canal, and the methods employed were those of the old days of barbarism. No less than a quarter of a million men were pressed into service. They were provided with no tools and received no pay. Working in the blazing sun, with bad arrangements for food and none at all for health, they yielded readily to sickness and disease, and 25,000 of them died in the trench.

It should be remembered that Egypt already has canals, and is continually adding to them. What she needs is more of that water which every year flows gaily through the country and out to sea. About 1870 some French

engineers persuaded the Egyptian Government to build two *barrages*, or walls, across the two mainstreams—the Rosetta and the Damietta—in the Delta, and thus hold up the water so that the height of the river above them might be increased by fifteen feet. For fifteen years men laboured at two huge arch viaducts of brick which were built on a foundation of stones and gravel thrown into the beds of the streams. In the lower portion were 132 openings, which could be closed by sliding doors or sluices. When these were closed the pressure of water above caused the viaducts to slide bodily downstream. The foundation was insecure.

At this time, the British had begun to be interested in Egyptian affairs, and Sir Colin Scott Moncrieff, who had done a great deal of engineering work in India, offered to make the barrage secure at a cost of £500,000. This was accomplished, and the water was allowed to rise six and a half feet above the usual level. At a later stage, weirs were built on the down-stream side to take off some of the pressure, so that the level was increased in all by over thirteen feet. Before the British occupied Egypt the area irrigated was 600,000 acres. After the weirs were added it increased to 1,700,000 acres.

But this was only a beginning. Soon after Lord Cromer became the British representative in Egypt, he appointed Mr. (afterwards Sir William) Willcocks to survey the Nile and report upon the best means of storing up its precious waters. How long do you think he took over it? A week? or a month? Remember that the Nile is a long river, and that recommendations which might lead to a vast expenditure of money must be based on exact knowledge. Not only must the size and speed of the flow be ascertained at every point, but the greatest, the least, and the average rises at flood-time,



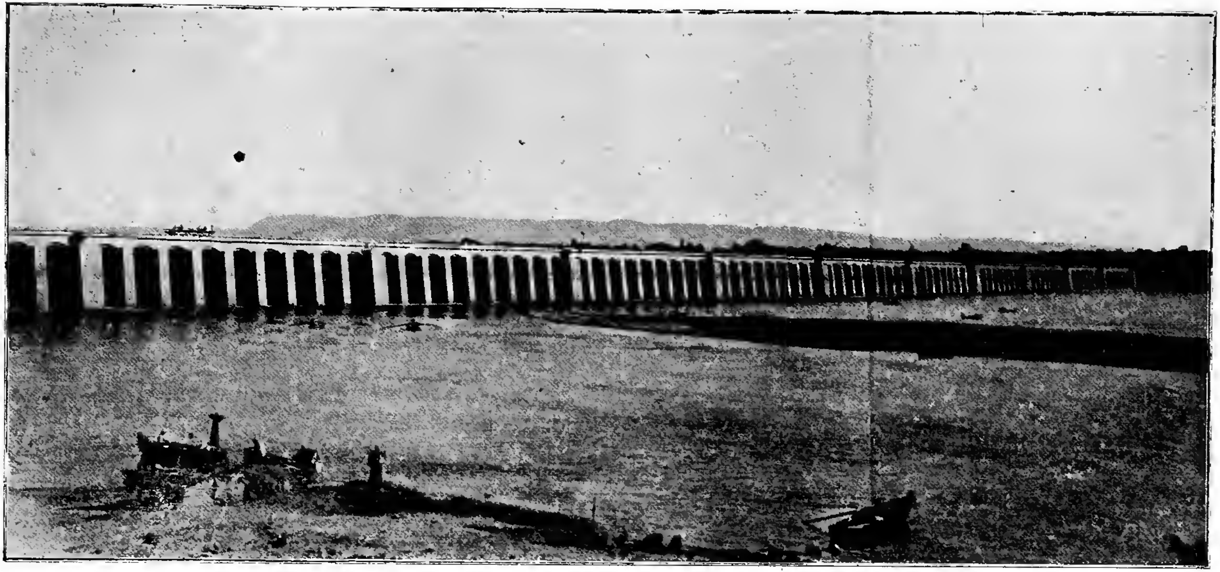

THE NILE VALLEY AND DAM.

and the nature and level of the surrounding land must also be known. So, accompanied by one Nubian servant, Mr. Willcocks spent three years in a close and accurate study of the Nile and its valley.

The problem that had to be solved was the irrigation of 30,000 acres of Middle Egypt and the Fayoum District, south of Cairo, which was unaffected by the Delta barrage. It was recommended that a barrage should be constructed at Assiout, the capital of Upper Egypt, where the river narrows down to half-a-mile in width. Just above this point water was admitted to the Ibrahim Canal, which runs for 200 miles through the land that requires to be watered. The main flood was not to be held back solely at Assiout, but also at Assouan, 350 miles farther up, where the river rushes over a rocky bed with granite cliffs on each side. At this point the stream is broken up by a number of rocky islands, past which it flows at the rate of sixteen miles an hour, forming the first of a series of cataracts between that point and Khartoum.

For some years the proposals were put on one side, because the Egyptian Government was not in a position to find the money. At last, a group of financiers, headed by Sir Ernest Cassel, came to its assistance, and the contract was let to Sir John Aird and Co., Sir Benjamin Baker becoming consulting engineer. Five years were allowed for the completion of the barrage and dam, but they were finished within four.

The barrage at Assiout is 2,750 feet long, and consists of 111 arches, each sixteen feet four inches in span, which can be closed by steel sluice-gates, sixteen feet high, sliding upwards and downwards in vertical grooves. The foundation is composed of a platform of masonry, protected on both upstream and downstream sides by



THE ASSIOUT BARRAGE.

cast-iron sheet piles driven through twenty-three feet of the sandy bottom of the river, and attached to the foundation wall with cement. This platform is eighty-seven feet long and ten feet thick. Upon it was built a wall forty-one feet high, supported on the downstream side by piers fifty-one feet deep.

The work could not be carried on when the river was in flood, so the most careful organisation was necessary to enable each part of it to be completed between November and July. Labour, however, was plentiful and cheap, though the workmen belonged to nearly every nationality under the sun. In 1900 the average number of men employed daily was 13,000, and these toiled away at the work, racing against time, in a temperature of 118° in the shade.

The method adopted was to clear the water out of the space in which the barrage was to be built, by means of a temporary embankment, or *sudd*, above and below. These sudds were composed of bags of sand, and in one season no less than 1,500,000 of them were required. Seventeen centrifugal pumps were then set to work to remove the water between the sudds, while the workmen made these secure with stones and clay. The suction of the pumps sometimes drew sand from below the concrete platform, and liquid cement had to be forced in. No fewer than 100 springs burst up through the sand bottom and had to be stopped up. But the barrage was completed in 1902, and, when the flood came down, the water rose twelve feet above its usual level.

## CHAPTER XII.

### The Assouan Dam.

While this task was being accomplished the far more difficult work at Assouan was in full swing. The first

proposal had been to erect a curved dam, like a masonry arch lying on its side, with the lower end abutting against the rocky walls between which the river flows. Such a dam would have been very strong and would have held up the water for another 120 feet, turning the valley beyond for nearly 200 miles into a great lake. But this would have caused the island of Philae with its fine ruins, a little higher upstream, to be submerged, and it was decided finally to make a straight masonry wall to hold up the water about sixty-seven feet.

The islands divide the main stream into a number of smaller ones—three on the east, one in the centre, and one on the west. The three easterly ones were closed first, and then the central one; finally, the sluices on the east were opened and the dam was built across the western channel.

The sudds were fixed on the downstream side first, as in the former case, but the roaring torrent made it quite impossible to start with sandbags. Huge pieces of rock, weighing from one to twelve tons each, were tumbled into the stream, and even some of them were immediately caught up and swept away. To prevent this several large blocks were fastened together by steel wire rope, run down to the river in a truck, and tipped, truck and all, into the water. As the sudd rose, smaller stones were thrown in on the upstream side to render it more watertight.

The upstream sudd was then taken in hand, and, as the current had been stopped, sandbags were sufficient. The upstream side of the first sudd was then packed with sandbags, the water was pumped out, and the excavation begun. Here another serious difficulty was met with: the rock in the bed of the river was rotten. The need for a good foundation had been shown in the building

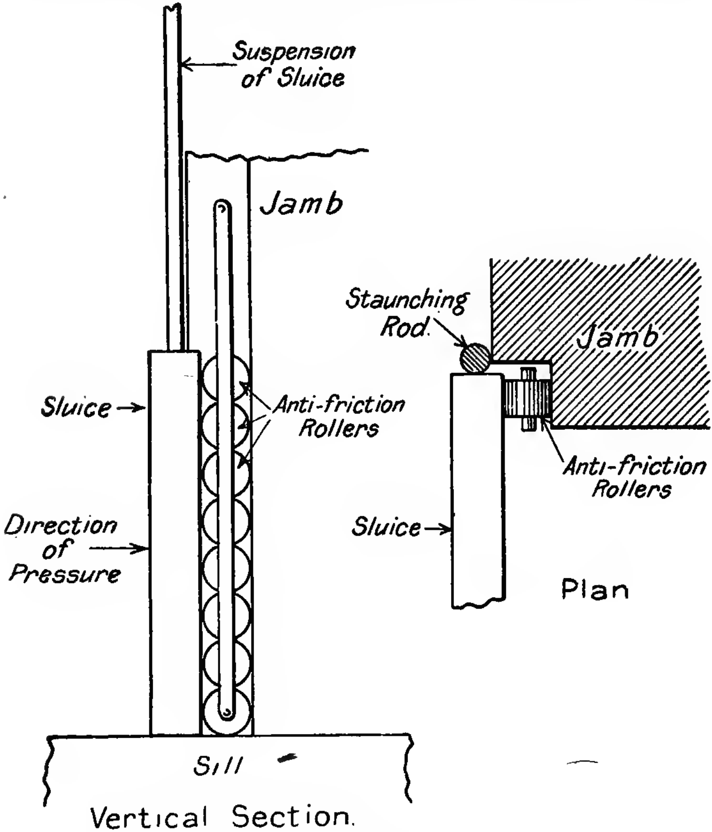
of the Delta barrage, which was only intended to raise the water fifteen feet; at Assouan the level was to be raised sixty-seven feet, and no chances could be taken. There was nothing for it but to blast out the soft and broken rock with dynamite until more solid material was reached.

The result of this unforeseen difficulty was that the foundations had to be carried forty feet lower and made thirty feet wider than was intended (that is, increased from seventy feet to 100 feet). Altogether, the amount of material which had to be removed was five times greater than had been estimated by the engineers, and, instead of the masonry wall weighing 500,000 tons, it weighed over 700,000 tons. It is one and a quarter miles long, 130 feet in its greatest height, 100 feet wide at the bottom, and twenty-four feet wide on the top.

In order to prevent the water from rising too high, there are 180 openings near the bottom of the dam wall, fitted with sluice-gates of the Stoney pattern. These show in an interesting way how special difficulties are overcome. The ordinary sluice-gate is simply a large steel shutter that slides up and down in vertical guides. It is supported by heavy weights on chains that pass over pulleys in the wall above, and it can usually be raised and lowered by a winch worked by hand. But the gates in the Assouan Dam were nearly seventy feet below the surface, and were thus under enormous pressure. Let us see what this was.

A cubic foot of water weighs $62\frac{1}{2}$ lb. The pressure, therefore, on an area of one foot, one foot deep, will be $62\frac{1}{2}$ lb.; at ten feet deep, 625 lb.; and at seventy feet deep, 4,375 lb.; which is very nearly two tons. Since a liquid exerts pressure equally in all directions, this is roughly the pressure which the sluice-gates have to bear

when the water behind them is at its greatest height. As each gate has an area of about 130 square feet, the total pressure on one gate is about 570,000 lb., or over 250 tons.




A SLUICE GATE OF THE STONEY PATTERN.

Of course, this enormous pressure would cause the gates to press so heavily against the downstream side of the grooves that no ordinary means would be sufficient

to move them. The Stoney sluice, however, has very wide grooves, along one face of which rollers are fitted. These offer very little resistance and enable the sluice-gate to be raised or lowered very easily. But, you will ask, how are the gates made watertight if they only rest against rollers at the back of the grooves? The provision for keeping out the water is really the most beautiful part of the whole contrivance. At the top corners of each gate, on the upstream side, are suspended two long pieces of bar-iron. These are free to swing, and, immediately the water begins to rush through, they fall into place and close the opening between the gate and its frame.

When the gates were closed and the water was allowed to rise to its full height of sixty-seven feet, a great lake 150 miles long was formed, and its contents were allowed to run out from time to time as the water between Assouan and Assiout was used up. The area of cultivated land soon increased and the demand for water became greater. The authorities began to wish that they had permitted the dam to be made higher, and troubled themselves less about the ruins of Philae. In 1905 the supply ran short, and in 1907 instructions were given to raise the dam by twenty-three feet, and to thicken it sufficiently to withstand the increased pressure.

You will think, perhaps, that this was an easy task. So it was, provided attention was paid to one little detail. The old masonry had been in place for over five years, and had cooled down; the new stones, exposed to the glare of a burning sun, would take a long time to reach the temperature of the old; and there was grave danger that cracks might occur after the additions had been made. This danger was guarded against in the following way. The new masonry wall was built about

six inches away from the old one, to which it was firmly connected by steel bars. This space was afterwards filled in with liquid cement, and, when the whole had set, the height was increased by the twenty-three feet required.

The work was finally completed by 1912. The amount

THE ASSOUAN DAM.

of water imprisoned is now usually two-and-a-half times what it was before, viz., 81,190,000 cubic feet, and another million acres of desert has been reclaimed. The cost of the original dam was £2,450,000 and of the extension £1,500,000. But, what is of greater importance, the cost of human life was comparatively small. The greatest precautions were taken to avoid death from sunstroke. At a number of points where the work was

going on, tents were provided, each containing a supply of ice, a bath, and a telephone. As soon as a man was overcome by the heat, he was placed in an ice-cold bath and a doctor was summoned by telephone. The consequence was that hardly a life was lost from sunstroke. Compare this with the loss of 25,000 lives in cutting the Alexandrian Canal seventy years before.

The Nile has always been an important means of transport and communication, as is every navigable river in countries where railways are few and far between. The Assouan Dam not only holds back the water, but is an effective barrier against ships; even a submarine would hardly be able to crawl through the tunnels at the bottom of the river. And as the movement of goods up and down the river was too important to be permitted to disappear, a navigation canal had to be built to enable boats to pass from below to above, and *vice versa.*

This was no light task. The difference of level is about 105 feet, and there are four sets of locks. The gates vary in size, the largest being originally over seventy-eight feet in height. When the dam was raised the locks had to be raised too, a larger pair of gates being constructed for the top entrance, and the other moved a step lower. As the seventy-eight-foot gates weighed ninety-two tons, they were not easy things to move. But there was no help for it; it had to be done.

## CHAPTER XIII.

### More about Egyptian Irrigation Canals.

THE storage of water is only one part of an irrigation scheme. In order to convey this water to the fields there must be a complete system of canals, just as there

must be a complete system of main and branch pipes in the water supply of a town. If the ground is very porous these must be lined with cement or concrete to prevent loss of water. The main canals and their branches must be properly fitted with sluice-gates, and every care must be taken not to waste the water which has cost so much in money, labour, and material. Even if there is no real waste, the amount supplied to different occupiers must be a fair proportion of the whole. This is so important that we may profitably devote a page or so to a description of the beautifully simple device which is largely used both in India and in Egypt to regulate the supply.

The first point to be noted is that the rate at which the water runs out of an ordinary sluice depends upon the depth. If the canal is full it flows out much faster than if it is nearly empty. The pressure tending to force the water out is proportional to the depth, being rather less than half a pound per square inch for each foot. There is, therefore, a tendency for water to run away unnecessarily when the canal is full, unless the man in charge of the sluice is skilful and reliable.

The "Module," as the apparatus to be described is called, is fitted in the sluice, and allows only the same quantity of water to pass whatever be the level of the canal. It depends upon the following principle. If you stir your tea round in your cup, the level falls in the centre and rises round the edge. When the tea is spinning round freely, a spoon held just below the surface near the edge rapidly reduces the speed, causing the level to fall round the edge, and rise again in the centre.

In the "Module," the water from the main canal enters a semicircular chamber, which causes it to spin round, and rise at the outer edge of the stream by an amount

that depends upon the speed at which it enters. The rising water comes into contact with a number of plates, called *baffle-plates*, which lie across its path in the upper part of the apparatus. These serve the same purpose as the spoon in the tea-cup experiment, and check the outflow. The apparatus is made so that, if the water issues with too high a velocity, it is returned through an overflow to the main canal.

It is adjusted to each opening once for all. After that, it cannot be interfered with, and is quite independent of the level of the canal, the dishonesty of an occupier, or the design or carelessness of any person who may chance to be in the neighbourhood. It is what has been aptly termed "fool-proof." It stands like a sentinel at the gate, and guards the precious waters from waste or extravagance.

The ditches by which the water is conveyed from the canals proper to the crops are simply little channels with earthen embankments. When water is required on the fields these embankments are broken down at one point with a spade and the water diverted by throwing in a few shovelsful of earth, or setting up a canvas barrier. You will see the necessity for extraordinary care in levelling when water is required to flow over many square miles of country.

There is one canal that differs so much from the others that if you had seen the men at work on its construction you might have been in doubt as to what it was for. Forty miles or so north of the Assouan Dam is a district of 12,000 acres, which lies some seventy-five feet or thereabouts above the highest level of the flood. Kom Ombo, therefore, is supplied by water from a reservoir into which it is pumped. From this reservoir the water is carried at the rate of twelve cubic yards a second


*By courtesy of the makers,* *Glenfield & Kennedy, Ltd., Kilmarnock.*

THE MODULE.

through a semicircular steel trough to the cultivated land, over which it is distributed by smaller canals or ditches.

The centre of interest here is the semi-circular trough, which lies like a huge house-gutter on the ground. It is a mile long, and fifteen and a half feet wide, and is constructed of steel plates a quarter of an inch thick, in 300 feet sections. It is built up almost like a ship, with strong T iron bars on the outside, thirty inches apart, and bars across the top to hold the sides together. The ends of each section rest in semi-circular grooves in large blocks of masonry, and the rest is supported by sand rammed underneath and against the sides.

Just as the steel rails on a railway have to be placed with their ends a short distance apart to allow for expansion and contraction, so also the Kom Ombo canal could not be made continuous through its length. The spaces between the ends of the sections in the masonry grooves are over six feet long, and the metal troughs rest upon a packing of rope soaked in tallow, which allows them to slide a little. The construction of this tube kept 7,000 men busy for some considerable time.

But enough has been said about the way in which the desert is reclaimed in Egypt, though not more than the work deserves. For the country is now growing large quantities of cotton and other things that the world needs; and the Assouan Dam is very nearly the biggest dam in the world.

## CHAPTER XIV.

### Fighting the Famine in India.

THE artificial watering of crops is carried out on a grander scale in India than in any other part of the world. The

*By courtesy of the Chief Irrigation Engineer, United Provinces, India.*

CUTTING A CANAL IN INDIA.

three great rivers of the northern plain, the Ganges, the Indus, and the Brahmapootra, are fed in part by the melting snows of the Himalayas, but the rivers of Central India derive their waters from the summer rains. When these are less copious than usual, the crops are burned up by the scorching rays of the tropical sun, and there is famine in the land. But during the last forty years the Government has spent more than £75,000,000 on irrigation works, and ensured a sufficient supply of water for more than 35,000,000 acres of territory.

The problem here is the same as in other countries. The river carries off the surplus waters to the sea, and, beyond carving out its bed in the land and thereby enabling navigation to be conducted on its surface, performs no useful service. To prevent this waste, the engineer dams the streams and distributes the water by means of a network of canals and ditches.

The first step was to store up water for the areas that were naturally fertile, upon which the 300,000,000 of people depended for food. Thus, on the right bank of the Ganges there is a canal, stretching from Hardwar to Cawnpore. It is more than 1,000 miles long, and feeds several thousand miles of branches which water the Doab between the Ganges and the Jumna. It is interesting to note that both "Doab" and "Mesopotamia" are both names that signify "land of two rivers."

But man is not satisfied with merely guarding against famine. He must needs stretch out his arm and reclaim the desert. On the west of the great plain is an arid region in which the rainfall is too small for plant life, but which is threaded by rivers flowing from the northern hills. These rivers have been brought under control, and their waters stored, and immense tracts of land, formerly inhospitable, have been rendered fruitful.

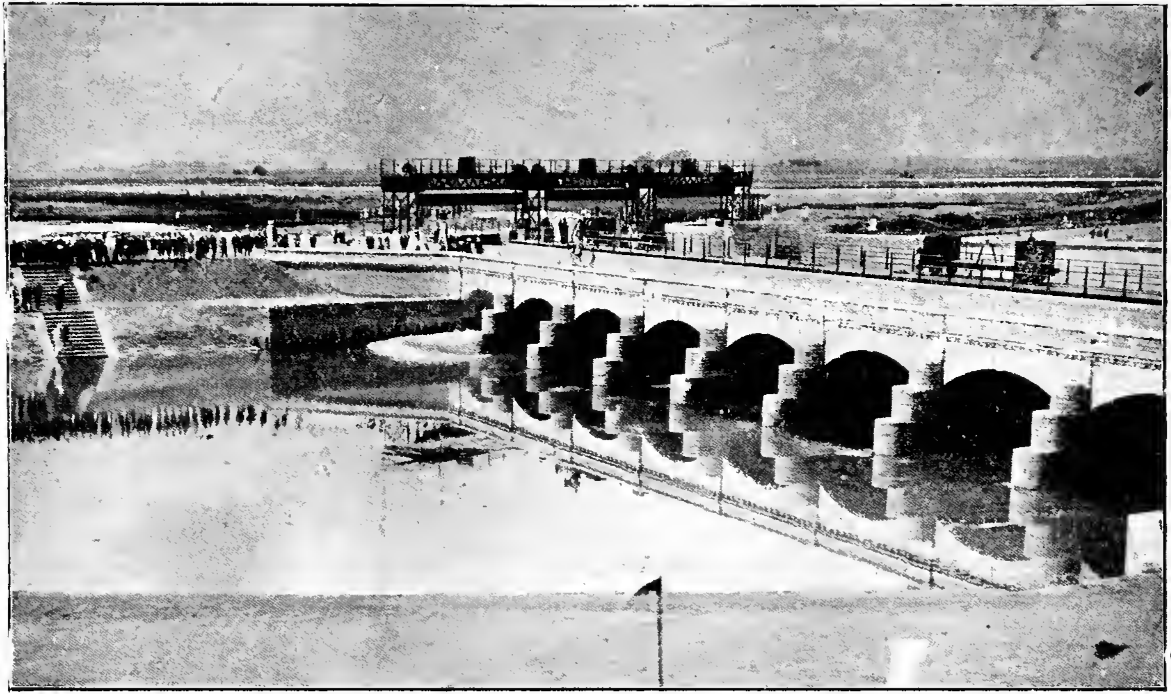
By courtesy of the Chief Irrigation Engineer, North West Frontier Province, India.

CONSTRUCTING AN INVERTED SIPHON FOR CARRYING WATER ACROSS A VALLEY.

The lower reach of the Indus is to the province of Sind what the Nile is to Egypt, but, instead of overflowing its banks, the river has been accustomed to carry its fertile mud and water to the sea. It is now dammed and "canalized" to irrigate the surrounding land, and a huge stretch of desert has been converted into a smiling plain upon which enormous crops can be grown.

From the point at which it leaves the mountains of Kashmir this river is brought into subjection, and there is now in process of construction a triple canal scheme which will increase the 6,559,280 acres of irrigated land in the Punjab, "the land of five rivers," to 8,430,515 acres. This is not the work of a month or a year, but of ten years, and some idea of the magnitude of the task will be gained from the statement that in 1912 the numbers of animals (chiefly donkeys) and men engaged on the work were 76,000 and 13,000 respectively. What this means in organisation—in feeding and management, as well as in supervision of the construction—is not easy to imagine. Twenty years ago the district round the Chenab River, in the Punjab, was a desert; it is now capable not only of growing the necessaries of life for those who till its soil, but also produces wheat, cotton, etc., to the value of £2,000,000 per annum, for export. Again, on the north-west frontier, the Upper Swat canal passes under Malakand Pass through a tunnel, two miles long, eighteen feet wide, and thirteen and a half feet high, which took three and a half years to make. The result will be an increase of more than 200,000 acres of cultivable land.

But this is not the only benefit from irrigation. The Upper and Lower Swat schemes cover arid regions which were inhabited by lawless tribes, who, being unable to engage in the peaceful pursuit of agriculture, spent their



*By courtesy of the Chief Irrigation Engineer, North West Frontier Province, India.*

THE HEAD OF THE UPPER SWAT CANAL.

lives in robbery and pillage. The watering of the land has converted them into busy farmers, with so much property of their own to look after that they let other peoples' goods alone.

While the danger of famine has thus been, or is rapidly being reduced, and while warlike tribes are being educated to peaceful pursuits, there is another wider, and perhaps more important result. So long as the inhabitants of a country are dependent for their food upon the caprice of Nature, they have little time for any occupation except hunting, fishing, or farming. But, when a plentiful supply is assured, they are free to enter upon manufacture, and there has been a vast development in this direction during the last twenty years. To-day India has many factories, well-organised and equipped with the most modern machinery, and is making for herself many things which formerly she bought from European nations. And this she owes in no small measure to the engineers who taught her how to control water.

## CHAPTER XV.

### The Desert Lands of Western America.

THE geography of North America tells you that a chain of lofty mountains runs down the western side from Alaska to the Isthmus of Panama. The warm winds from the Pacific deposit their moisture on the western slopes and blow unkindly over the plains between the ranges and the Mississippi. In some districts, nothing can be grown at all without an artificial water supply; in others, water is needed in dry seasons or to obtain the full yield of the soil. Until 1902 the Government of the United States did not concern itself with the matter,

but private individuals had constructed dams and canals which watered nearly 10,000,000 acres. On this land there were more than 34,000 farms and the cost had been nearly £20,000,000.

The United States is a big country, but it has a rapidly increasing population, which is now more than 90,000,000. Twenty years ago they were exporting large quantities of foodstuffs—corn and meat, but the amount has become smaller and smaller, until at the present time they are beginning to import them. The land under cultivation is incapable of yielding the amount which the growing population requires. But there are large areas which produce nothing, and in 1902 the Government established a "Reclamation Service," to deal with waste-lands. A survey showed that irrigation would render it possible to cultivate 30,000,000 acres, which otherwise would lie idle and unproductive. So at a cost of £14,000,000, a scheme was set on foot whereby, by 1911, nearly 2,000,000 acres would be watered. The money was found by the sale of public land in lots of from forty to 160 acres, at prices depending upon the cost of the irrigation scheme, and the working expenses are to be covered by an annual charge for the water.

The first million acres will support 21,000 people on the farms, and steps have been taken to provide proper training for those who take them up. "Demonstration farms," where the settlers can see how the operations should be carried out, and what crops should be grown, have been established. When the whole 30,000,000 acres have been brought into cultivation they will provide homes for 15,000,000 people—about a third of the present population of the United Kingdom. It is estimated that half of these will be engaged on the farms, and half in the cities.

*By courtesy of the Chief Engineer,* *U.S. Reclamation Service.*

LAND IN ARIZONA BEFORE IRRIGATION.

THE SAME LAND AFTER IRRIGATION.

The immensity of this scheme will best be understood if a short account is given of the work required for the first 2,000,000 acres and their paltry 21,000 inhabitants. To begin with, a large dam, the Laguna Dam, has been thrown across the Colorado River near Yuma in Arizona. This is merely a weir which holds up the water so that it can flow into two canals serving for 100,000 acres.

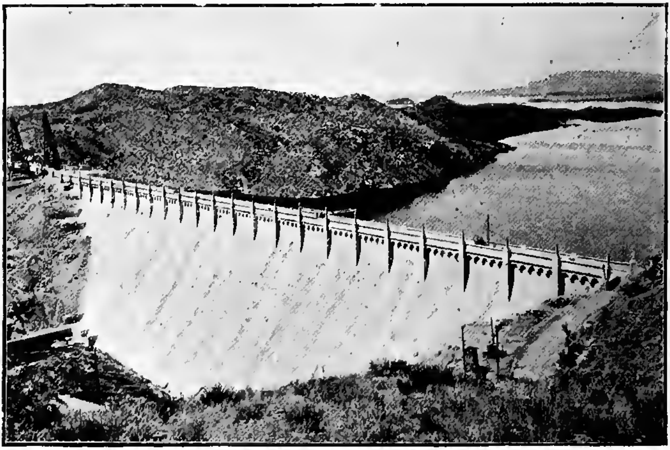
Again in Arizona, the mighty Roosevelt Dam has been thrown across the Salt River where it flows in a deep, rocky cañon. This dam is 284 feet high and converts the river above it into a lake more than twenty-five square miles in area. To convey the machinery and material a road had to be cut over the mountains. About 160,000 acres of low-lying land will be irrigated by canal in the ordinary way. But there are 50,000 acres more of thirsty land lying at a higher level. A special canal eighteen and a half miles long has been cut, and through this the water flows to a power station, where it drives turbines, which, in their turn, drive pumps. These pumps attack the underground waters and fill a reservoir which serves the higher ground.

The Shoshone Dam in Wyoming is only 175 feet long, but it is 310 feet high. Here again a road had to be made over the mountains. The water leaves the reservoir in an open canal, but thirty miles below the dam it passes through a tunnel three and a quarter miles long, before proceeding to water 100,000 acres.

The Pathfinder Dam across the North Platte River serves land both in Nebraska and Wyoming. The canal is ninety-five miles long and, owing to the porous character of the soil, it had to be lined with concrete for many miles. It waters 110,000 acres, but when the scheme is complete, four times that area will be irrigated. The Snake River in Idaho is also being controlled. It feeds 130 miles of

canal and 190 miles of ditches. At present only 100,000 acres are watered, but this will shortly be increased to 370,000 acres.

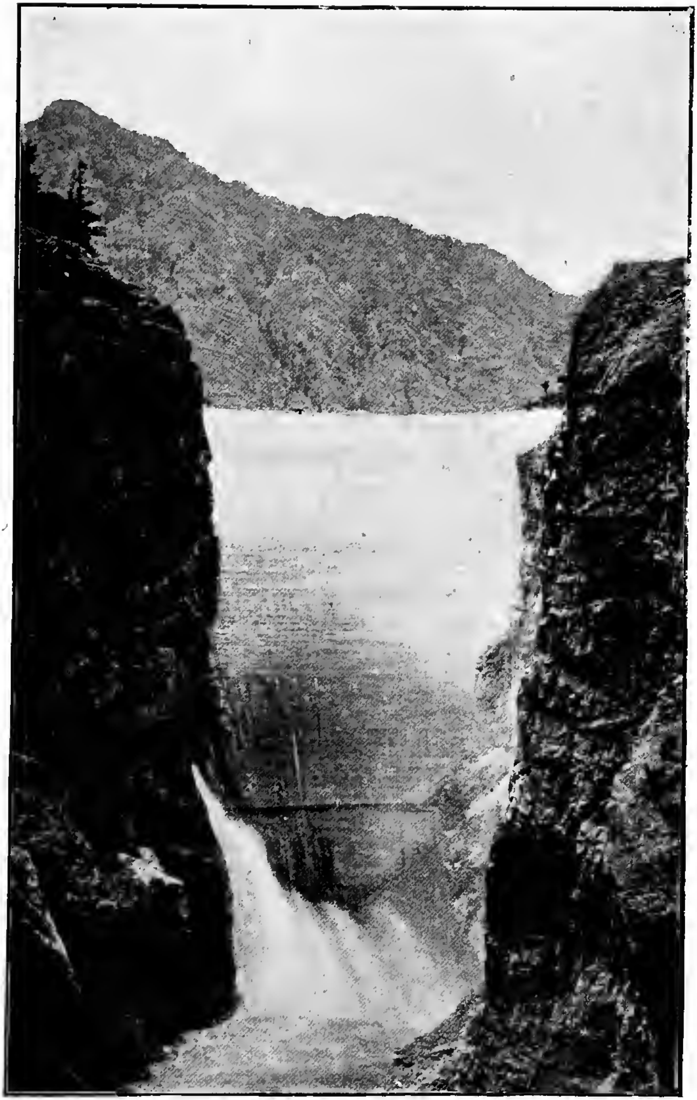
The most interesting of all schemes, however, is that of the Uncompahgre Valley in South-west Colorado, and this must be included in a list which may easily be made so long as to become tedious. Side by side, and only



*By courtesy of the Chief Engineer, United States Reclamation Service.*

ELEPHANT BUTTE DAM.
RIO GRANDE PROJECT, U.S.A.

ten miles apart, run the rivers Gunnison and Uncompahgre. The former is a vigorous torrent in a deep rocky cañon ; the latter a trickling stream in a wide, open valley of 700,000 acres. Between them rises a range of mountains towering to a height of 2,000 feet. The steep, rocky walls of the Gunnison Cañon are useless to man ; the soil of the Uncompahgre Valley would be fertile if only it were well watered. So the Reclamation



*By courtesy of the Chief Engineer, United States Reclamation Service.*

SHOSHONE STORAGE DAM, WYOMING, U.S.A.

officers decided to carry the waters of the Gunnison into the Uncompahgre Desert, which lies at a lower level.

Before the Gunnison could be dammed, a road, sixteen miles long, had to be cut in the side of the gorge; and, when it was dammed, a tunnel, six miles long, twelve feet wide, and ten and a half feet high, had to be driven through the mountain barrier. But the task was accomplished, and 140,000 acres of rich land have been brought into use.

This list is long enough, even though it is only a small part of a small beginning. There are altogether twenty-eight schemes for the first 2,000,000 acres, and the success which has already been attained will ensure the progress of the enterprise. The farmers who have settled on the land, which was once desert, find it rich beyond expectation. If they grow corn they obtain forty bushels as compared with fifteen in the Eastern States. But they are mainly growing hay and forage, especially *alfalfa*, or lucerne, for stock.

The plan is to feed the cattle and sheep on the grassy uplands in summer, and bring them into the irrigated valley in winter. From this land they can obtain five tons of alfalfa per acre, worth $5 a ton, and in one case no less than 30,000 sheep have been fed in this way. But remember that the population is growing very rapidly, and nearly twenty years have been occupied in providing for less than one-tenth of the 15,000,000 people which the irrigated land has been estimated to support.

# SECTION IV

## TRANSPORTATION CANALS AND THEIR MAKERS.

## CHAPTER XVI.

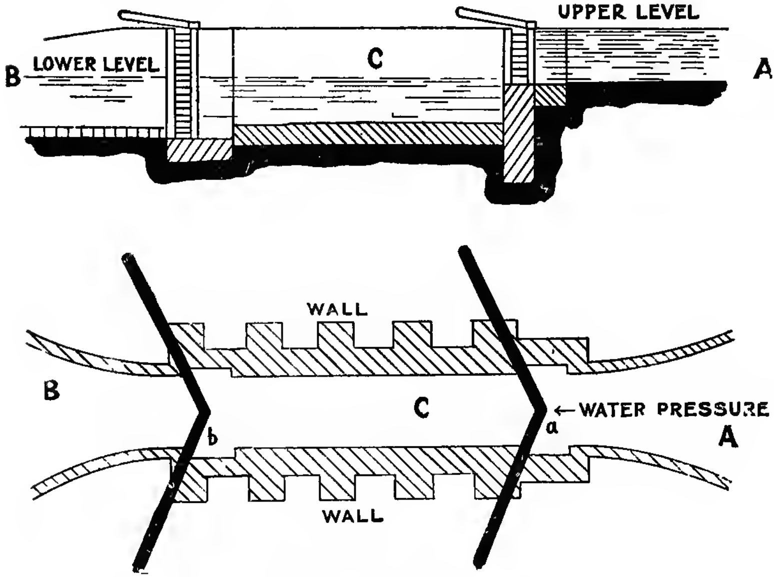
### Locks and Early Canals.

EVERY man and woman in the world is a canal maker at heart. The first thing we wish to do at the seaside is to dig a ditch into which the water will flow when the tide comes rolling in. And what a world of fancy we weave about it! The few square yards of sand to which our operations are confined are to us a vast area of country covered with lofty mountains and rugged valleys, through and across which the channel is cut by the vigorously wielded spade. The tiny vessel, launched with great expectations upon the artificial waterway, is in imagination a monster ship, laden with merchandise from far-off lands. And when the tide destroys the patient labour of hours, we feel a sorrow almost as overpowering as that which falls upon the engineer who sees the great works which have arisen under his guidance wiped out by an unexpected outbreak of natural forces.

Go back as far as you like in the history of the world, and you cannot find a time when men did not make canals. There were canals in Babylon, canals in Egypt, and canals in China, in the last case more than 800 miles long and 200 feet broad. But they differed from those of modern times in being simply level ditches; for lock-gates, by the use of which boats are carried up and down

the hillsides, were not invented until the fourteenth century. Whether they were first used by the Italians or by the Dutch is a disputed question which we can afford to ignore.

In order to understand what lock-gates are you should see them working. The stream is here confined between




DIAGRAMS OF A LOCK.

masonry or concrete walls, with perpendicular sides, and at each end is a pair of timber or steel doors mounted on hinges so that they can swing round and close the opening between the walls. Consider now the simplest case, in which a canal communicates with a tidal river or the sea. The ordinary level of water in the canal is that of high tide, and when the tide is up the gates

can be opened for boats to pass in and out. But as the tide falls the gates must be closed to prevent the water in the canal from running out again. Two pairs of gates, a short distance apart, enable the entrance to be used at any time if there is a sufficient depth of water outside, because the space between, or "lock," can be emptied to the level of the water below, or filled from above. The small amount required to fill the lock has very little effect on the level of the canal, which may be hundreds of times longer.

It will easily be seen how a hill can be climbed by means of a series of locks. Since the passage of boats in this way can only be managed by first running water out and then running it in, an inland canal would soon be emptied if means were not taken to supply it with water. So every canal that is not a sea-level cut depends upon an upland lake, or storage reservoir, at a higher level than any point in the canal itself. If a reservoir has to be specially constructed, it adds greatly to the cost.

This has been avoided in some cases by lifting the boats from one level to another by hydraulic lifts—a method which is adopted on the Trent and Mersey Canal among many others. The lower portion of the canal ends in a metal tank which can be shut off by double sliding doors, two in the ends of the canal and two in the tank. The latter is supported on hydraulic jacks which raise it to the level of the upper section. Doors, similar to those that permitted the boat to enter, now permit it to leave. But, though this method avoids a waste of water, it requires water at high pressure to operate the jacks.

If you have ever visited Holland you will understand why the Dutch became so famous for their canals. The land is low and flat. Much of it has been reclaimed from the sea, which is in places only kept out by great

embankments or "dykes"; and wide ditches were necessary in order to drain the pastures. What is more natural, then, than to use these waterways for transport, and, having seen how admirably they serve the purpose, to cut more and more of them, until they form a wonderful network all over the country.

The next people to make large use of water transport were the French, and they soon attained equal skill. Indeed, one of the works is worthy to rank with many of more recent times. The canal which flows through Languedoc, and was completed in 1689, connects the Bay of Biscay with the Mediterranean. It is 158 miles long, sixty feet wide, and 600 feet above sea-level at its highest point. The hills that lie in its track are climbed by more than 100 locks, and it threads its way across the valleys through more than fifty aqueducts. The man who constructed it fought with difficulty after difficulty for fifteen years, and died before it was completed.

But these canals were made more than three hundred years ago. They were an advantage, certainly; but their value was not felt so suddenly or so strongly as that of later ones that were built in the days of the Industrial Revolution. For them we must turn to England, at the period when Watt's steam engine was transforming industry and building up that manufacturing supremacy which was unchallenged for a hundred years.

## CHAPTER XVII.

### The Canals of the Industrial Revolution.

It is impossible to write anything about early English canals without giving an account of James Brindley. Any one knowing him as a boy, or even as a young man,

would have said that he was the most unlikely person in the country ever to exercise any influence upon its progress. Brindley's father was a small farmer who lived between Buxton and Macclesfield. How humble his home was you will understand from the fact that, when the family left the district, it was allowed to fall to pieces, and the stones were used for other buildings. The boy was born in 1716. At an early age he was set to work at such labour as was to be found in the neighbourhood, but his mind was bent on mechanical contrivances, and when he was seventeen he was apprenticed to a millwright and wheelwright at Sutton, near Macclesfield. Here he got very little instruction, having to pick up the tricks of his trade for himself. His master had the impression at first that he was a poor, unintelligent workman; but before Brindley had been at the work three years he displayed extraordinary mechanical ability, and at the conclusion of his apprenticeship he practically managed the business. When his master died, Brindley went to Leek, in Staffordshire, and set up in

JAMES BRINDLEY.

business for himself. He was then twenty-six years old, uneducated so far as book knowledge went, but with a tremendous interest in, and love for, his work.

And of what his work was like, you, who live in the twentieth century, can form only an imperfect idea. Machinery was just beginning to be employed, and if anything went wrong, the millwright was called in to set it going again. At the same time he might be called upon to make new machines, and for this he had to prepare all his own material. If timber were required, he selected a growing tree, bought and felled it, and dragged it to his workshop. As at first Brindley employed neither apprentice nor journeyman, he was frequently in need of strong arms and a resolute heart.

But to get on to Brindley's canals. Manchester wanted coal, and the coal was in the Duke of Bridgewater's pits at Worsley, seven miles away. Every day pack-horses, carrying two baskets, each thirty inches long, twenty inches wide, and ten inches deep, and holding about 280 lb. of coal, set off from the pits to the town. This mode of transport was unsatisfactory alike to those who wanted to sell and to those who wanted to buy. So, in 1759, the Duke obtained powers from Parliament to construct a canal.

The first intention was to carry the canal from Worsley, which lies on high ground to the east of Chat Moss, down to the Irwell by a series of locks, and then up the other side of the valley in the same way. But when Brindley was asked to undertake the work he advised the Duke to carry the canal right across the valley on a viaduct. The bridge for this purpose had to be 200 yards long and twelve yards wide, and was far larger than anything that had previously been undertaken in this country. People said the scheme was that of a madman, but the

Duke placed confidence in his engineer and the plan was carried through. The viaduct was built of stone, and had sixty-three semicircular arches, which carried the canal over the River Irwell at a height of thirty-nine feet. The channel in which the water flowed was made water-tight with "puddle"—a mixture of clay and water, well mixed, and applied in several layers until it was about

A BARGE ON A CANAL.

three feet thick. It was carried across Stretford Meadows on an embankment 900 yards long, 112 feet wide at the base, twenty-four feet wide at the top, and about seventeen feet high.

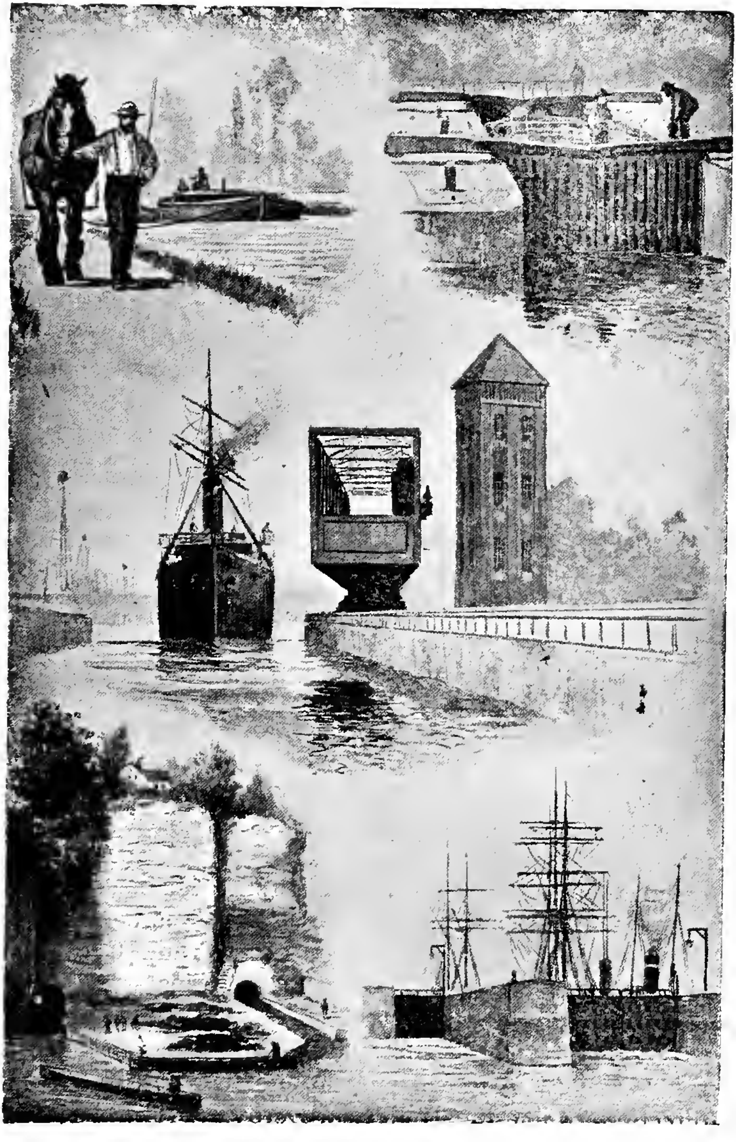
At the Worsley end, the canal was continued into the workings through a tunnel in the face of a cliff, so that the coal could be loaded directly into barges from the mine. At first it pursued its underground path only for about a mile, but fifty years later it had thrown

out underground channels in all directions, these amounting to no less than forty miles. At the Manchester end, the trouble of pulling the carts from the canal level up Castle Hill was so great that Brindley carried the canal into a tunnel, and then hauled the coal up a shaft by means of a water-wheel thirty feet in diameter worked by a waterfall on the River Medlock.

But to recount even a fraction of the ingenious contrivances of this man, who made up in industry and perseverance what he lacked in education, would take up a whole volume. To be brief, the Bridgewater Canal was extended to Liverpool, where at a later date it was joined by the Grand Trunk Canal, which connects the Mersey and the Trent. Before Brindley's time the cost of transport of goods between Liverpool and Manchester was 40s. a ton by road and 12s. a ton by water. The latter immediately fell to 6s. a ton.

In all his works he avoided locks wherever that could be done. "Water is a giant," said he; "let him, therefore, be laid on his back." And so he made use of an aqueduct to cross a valley, and if a hill stood in his way he drove a hole through it For example, under Harecastle Hill, the Grand Trunk Canal passes through a tunnel one and a half miles in length. There is no room for a towing-path, and the subterranean voyage is made by men lying on their backs on the deck and pushing at the roof and sides with their feet. There are several shorter tunnels, besides a number of locks.

The principle which Brindley followed is best illustrated by the extension of the Bridgewater Canal to Liverpool. Here the whole of the locks are found near Runcorn, where the canal descends, as it were, by a flight of "water-steps," into the River Mersey. The fall is seventy-nine feet in a distance of 5·7 furlongs.



CANAL SCENES.

The general arrangements for carrying on the work quickly were not one whit inferior to those employed in later times. A blacksmith's shop was fitted up on one barge, a carpenter's shop on another, and a mason's shop on a third. These were hauled up and down the canal to whatever place they were required. In a similar way, all the stone and clay was transported as much as possible by water, to save expense. All this involved a great deal of organisation and careful oversight, and to the responsibility of construction was added the trouble of dealing with those through whose land the waterway passed; for, though the opponents had been beaten in Parliament, they were ready to seize upon any excuse for hampering the project.

One of Brindley's most ingenious contrivances was a special flood-valve to prevent the damage which had been prophesied from any unforeseen occurences. The valve consisted of a flap or lid, covering an opening in the bottom of the canal and arranged to open if the water ran with more than a certain velocity. It was thus emptied into a drain or natural watercourse, instead of overflowing the banks and damaging the fields on either side. For the same reason he preferred to feed his canals from an independent reservoir, the outflow from which he could control, rather than to connect it with a river which might become unmanageable.

Before the Duke's canal to Liverpool was completed, Brindley was engaged on the Grand Trunk Canal for which powers were obtained in 1766. This starts from the Duke's canal at Preston-on-the-Hill, near Runcorn, runs down through the middle of Cheshire, then through the Potteries, and then curls round in a north-easterly direction, to join the Trent near Derby. From this point navigation is possible to the Humber. The Wolverhampton

Canal, for which sanction had been obtained about the same time, runs from Bewdley, on the Severn, to the Trent not far from Haywood Mill. The ports of Liverpool, Hull, and Bristol were thus put into communication with one another.

The total length of the Grand Trunk Canal was 139½ miles, making it by far the most important work of its kind in the country. The greatest care was taken to keep on the level, but it was impossible to avoid a rise of 395 feet to Harecastle Tunnel, and a fall of 288 feet to the Trent Valley beyond. These required thirty-six and forty locks respectively. On the other hand, from Preston Brook to Middlewich is a dead level, and boats can travel from Manchester into Cheshire for seventy miles without passing through a single lock. The original canal was from twenty-eight to thirty-one feet wide at the top, and from four and a half to five and a half feet deep. It spanned rivers in five large viaducts, and valleys and smaller streams in 160, and it crossed no fewer than 309 roads. Within the first two years seventy-two miles had been cut, but the Harecastle Tunnel took eleven years to complete.

By that time Brindley's race was run. When he died, in 1772, in the 56th year of his age, he had laid out and, in the main, constructed, more than 360 miles of canals, and every bit of the work had had to be devised by himself. His lack of education had prevented him from acquiring knowledge from books. He could scarcely read English, still less the learned volumes on canal construction which had been published by French and Italian writers; and for the whole of the time he worked for the Duke of Bridgewater he received no more than 3s. 6d. a day and his expenses. From the note-books he has left behind, it is clear that these were small, for his dinner

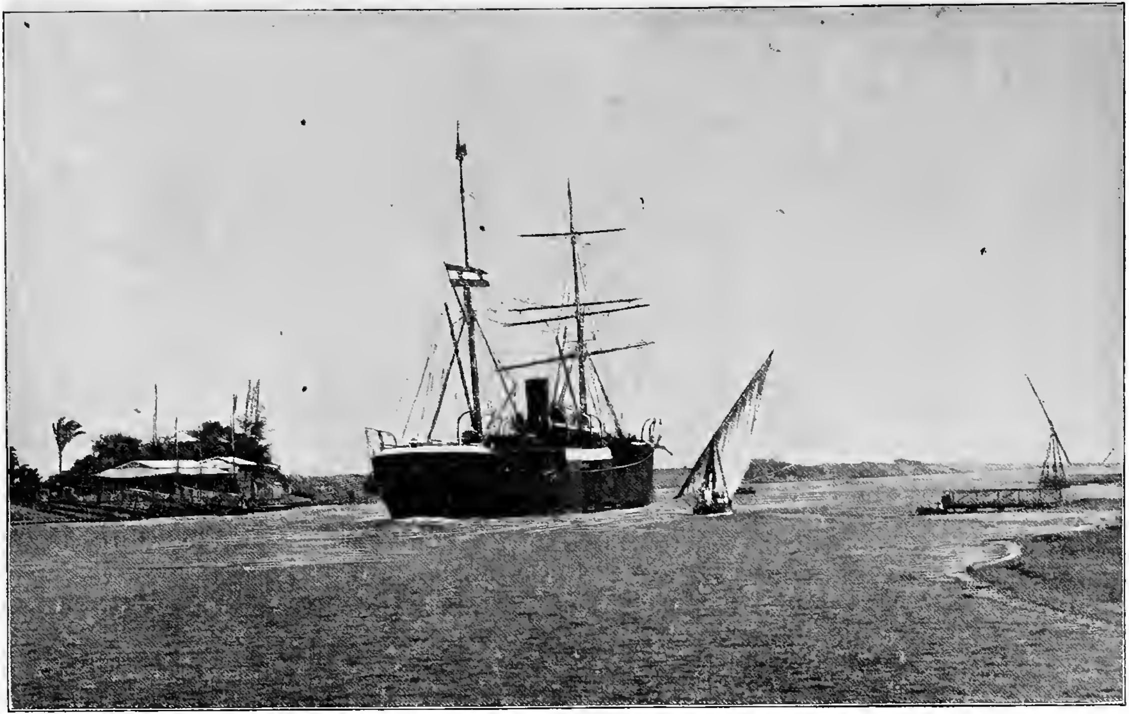
is rarely entered as amounting to more than eightpence. He gave manufacturers that start which enabled them to take advantage of the locomotive when it came; and by bringing coal and the produce of the land to the towns cheaply, he added immeasurably to the comforts of eighteenth century life in England.

## CHAPTER XVIII.

### The High Road to India.

If you look at a map of Africa you will see that the continent is very nearly surrounded by water. Save for the narrow neck of land at the north-east corner, which in olden times formed one of the land-bridges by which men conducted commerce or made warlike expeditions, its boundaries are washed by the waves of the sea. No doubt, in past times, the Dark Continent was wholly surrounded by water, and the Red Sea was one with the Mediterranean. But drifted sand from the desert, and Nile mud from the Abyssinian uplands, combined to form that strip of land which caused the gallant East-Indiamen of the early nineteenth century to sail all round the Cape of Good Hope on their voyages to and from the Indian Ocean.

This defect in the distribution of land and water was not a new discovery, and the modern world cannot claim all the credit for attempting to remove it. The Greek historian, Herodotus, describes a canal that was constructed across the Delta about 600 B.C. It was ninety-two miles long, 100 feet wide, and twenty feet deep. Some sixty miles were cut by hand, the rest passing through shallow lakes. The journey through it took four



A SHIP PASSING THROUGH THE SUEZ CANAL.

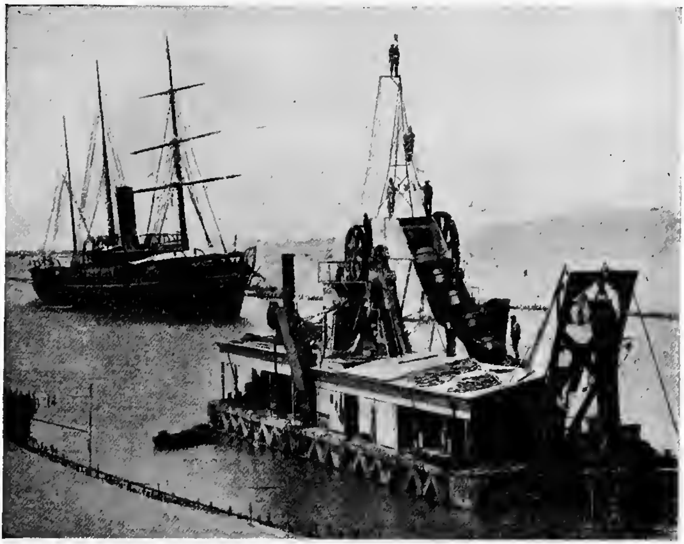
days. Gradually sand and mud encroached upon it, until it was no longer navigable ; but in the seventh century of the Christian era it was re-opened by the Caliph Omen.

Eight hundred years later, the merchants of the great trading cities of mediaeval Italy—Venice and Genoa—were impressed with the importance of a shorter way to the Far East. They realised that a canal was necessary, but for various reasons the project was only talked about, and not undertaken. The same fate befell the suggestion of Napoleon, who gave a good deal of thought to its problems. The proposal which may be regarded as the real starting-point came from Père Enfantin, who brought the matter to the notice of Ferdinand de Lesseps, the French Vice-Consul, and Mehemet Ali, who was then the ruling Pasha.

From that time forward de Lesseps devoted himself to the problem. An immediate start was prevented by an outbreak of plague, and it was 1845 before any real step could be taken. Then there was the usual reference to other engineers, who reported unfavourably upon the scheme. One of these was Robert Stephenson, who did not think it was impossible, but said that the cost would be so great that it would not pay. How far that was a sound forecast we shall see presently. Another English engineer, John Hawkshaw, was, however, a strong supporter, and de Lesseps said afterwards that without his help the canal would never have been completed.

While expert advice was being taken, time was passing. It was 1854 before the scheme was approved by the Viceroy, and 1860 before the work began. Before a spadeful of earth had been dug, therefore, de Lesseps had spent twenty-seven years in the struggle. But success was achieved, and on 16th November, 1869, the canal was thrown open to the world's shipping.

The Suez Canal differs in several respects from all those we have been considering. In the first place it is a "sea-level cut," opening from a tideless sea at each end, and, therefore, requiring no expensive locks and gates. Secondly, it was driven for the greater part of the way through soft material. Thirdly, it is a ship



A DREDGER.

canal, with a depth and breadth five times as great as a canal intended to carry only barges upon its surface.

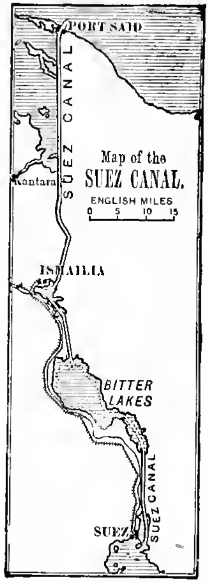
The first step was to protect the embankments from the swell of the Mediterranean, and this was effected by two large breakwaters at Port Said. They are huge walls, rising from the bottom of the sea to a height of several feet above the surface, deflecting currents and forming a

barrier to the waves. There was no stone in the neighbourhood, so immense concrete blocks were made, and tipped out into the sea until they rose above the surface. Each weighed from ten to twenty tons, and more than 25,000 of them were required.

The canal is 100 miles long, and was originally twenty-five yards wide, with lengths fifty yards wide at intervals of five or six miles, to permit of ships passing one another. At a later date the width was increased to thirty-six yards, and the depth to thirty-one feet. For two-thirds of the distance the channel had to be cut through shallow lakes, which gave nearly as much trouble as the solid ground. The usual method of digging out a dry trench to the proper depth, and then admitting water, was not followed. The spade was only used until a ditch five or six feet below the sea-level had been made, and then the water was admitted and the rest of the work was carried out by dredgers. These were of two kinds, fixed and floating. The former consisted of a large raft, with a hole in the centre over which was erected an endless chain fitted with buckets. The height of the chain was adjusted, so that when the wheels to which it hung were turned, the buckets scraped out grooves in the canal bottom. They came up full of water, sand, and mud, which they emptied into a long shoot, or trough, leading to the top of the embankment. The dredger was moored in position, and moved from time to time to a fresh place. The floating dredgers were similar in construction, but smaller. They were attended by barges, each carrying a number of railway wagons into which the mud was poured. From time to time, as the trucks were filled, the barges were hauled off to a sort of quay, fitted with hoists by which the trucks were drawn up the bank and emptied. These floating dredgers were more manageable

than the larger ones, but were not capable of removing so much material at a time.

Let us now trace the course of the canal from Port Said to the Red Sea. The first twenty-eight miles pass through Lake Menzaleh, a shallow lagoon across which the canal is enclosed by sand embankments. The next fifteen miles pass over the almost dry bed of Lake Ballah, where it is again retained between huge banks of sand. The third stretch of importance is Lake Timsah, which, although originally a lake, had long been dry when the canal was made. The sea was admitted to it, and it is now in very truth a lake, and upon its banks is the town of Ismailia. Then come eight miles of desert, where an unexpected difficulty arose. The ground is here about forty feet above the sea-level, but no difficulty was anticipated in cutting through it. However, after a good deal of progress had been made, a lion stood in the path in the shape of a huge mass of rock, eighty feet in length measured along the line of the canal, and only twelve feet below the water-level. A raft was moored over it, holes were drilled by long poles shod with steel, and then gunpowder was used to break the rock into pieces. After great labour the obstruction was removed.



MAP OF THE SUEZ CANAL.

The canal next enters the region of the Bitter Lakes, so called because, as the water dried up, they had become salter and salter. It was really a sandy hollow containing pools of brackish water. The sea was again admitted,

so that it now forms a lake twenty miles long and six or seven miles wide. This is the only portion of the canal in which a cutting was not required. From the Bitter Lakes the canal was constructed in the ordinary way to the Red Sea end.

The saving of time on a voyage to the East was three weeks, for the distance to be covered is 6,000 miles less than round the Cape of Good Hope. The work cost £20,000,000 and occupied an army of 250,000 men for ten years. In 1870, the year after it was opened, 451 ships took advantage of it; in 1871, 765; and in 1910 no less than 4,533—more than twelve a day. The income is now about £60,000,000 per annum, and about £4,000,000 of shares which the British Government bought in 1875 are now worth more than £30,000,000. Yet it was prophesied that the canal would not pay.

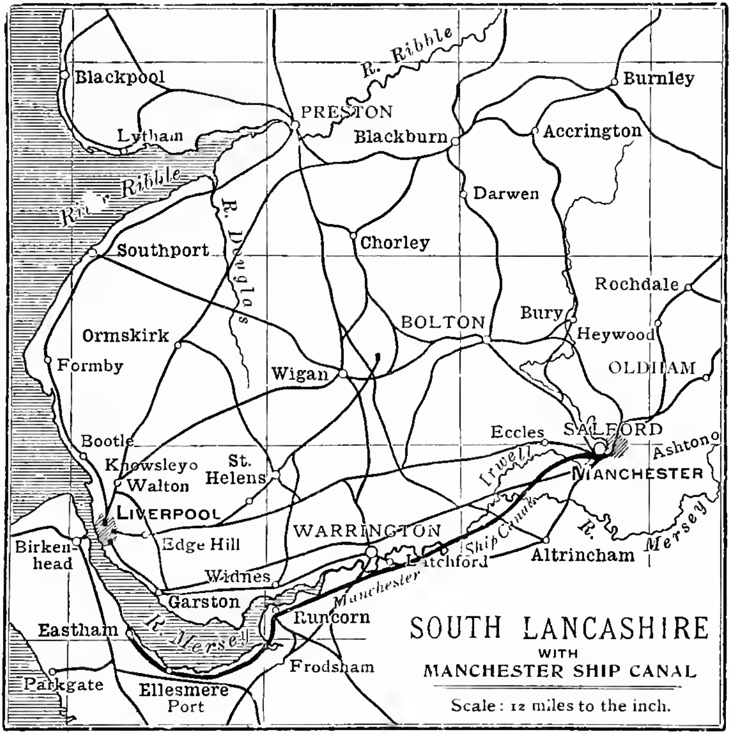
## CHAPTER XIX.

### Bringing the Sea to Manchester.

MANCHESTER is rather more than thirty miles from the mouth of the Mersey, and, as every one knows, it is the centre of the cotton trade. For this purpose it requires raw cotton, which grows chiefly in the hot, moist climate of the Southern States of America. For a hundred years the cotton grower has looked to the Manchester merchant and the Lancashire spinner to buy from him, and has sent his goods to the port nearest to his customer in order to save on the cost of land transport. This trade has always bound Liverpool and Manchester closely together. They were the first two important towns to be connected by canal and railway; but neither of these

means of transport could keep pace with the growing needs of industry.

The success of the Suez Canal probably led to the




A MAP OF THE MANCHESTER SHIP CANAL.

desire of Manchester to have docks of her own. Dock dues and railway rates were high, and the expense of unloading and reloading added to the cost of both imported and exported goods. Consequently, in 1882, definite steps were taken to establish a canal through

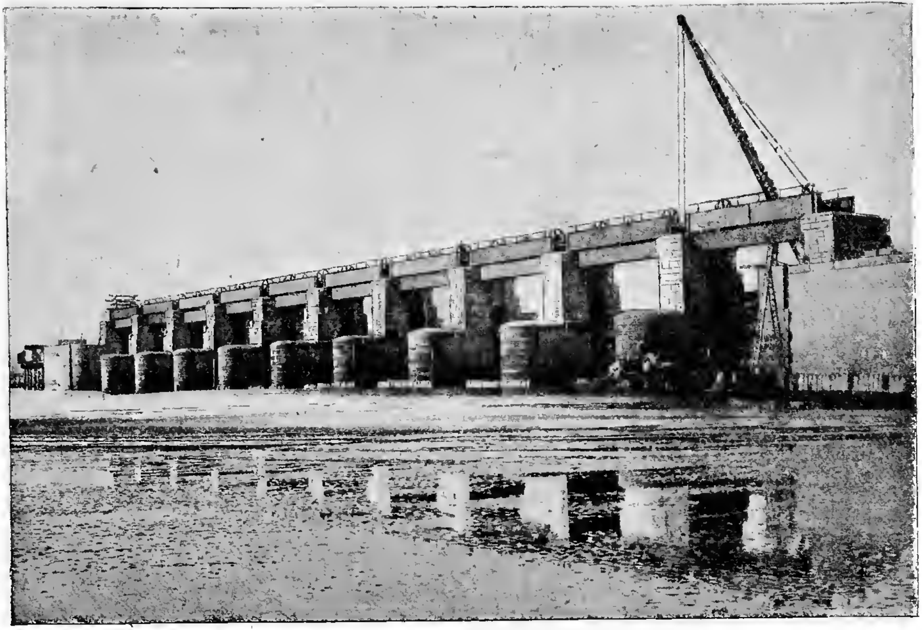
which large ships could pass directly to the warehouses of the cotton city.

Two proposals were considered. One was to cut a sea-level canal which would only need locks at the outer end; but, as Manchester is sixty feet above sea-level, the goods would have had to be hauled up-hill when they reached it. The other plan, proposed by Mr. Leader Williams, was for an ordinary canal, starting from Runcorn, and following the river valley. This was adopted, and an Act of Parliament was obtained, the preliminary expenses amounting to no less than £150,000!

The capital required was estimated at £8,000,000, and the contract for construction was let in 1887 for £5,750,000. The time required for completion was estimated at five years, and the canal was to be ready by January 1st, 1892.

The difficulties of constructing the first really great ship canal, in which vessels over 500 feet long, carrying up to 9,000 tons of cargo, had to be lifted sixty feet above the sea-level, were far greater than those encountered at Suez.

The sea end of the canal is at Eastham on the banks of the Mersey, between Liverpool and Runcorn. For about thirteen miles it runs along the side of the river, from which it is protected by embankments, some of earth, some of rubble, and some of concrete. One portion of the embankments rests on huge wooden piles, which were driven into the sand in two rows seventy-eight feet apart, by the use of high pressure water jets, delivered through narrow tubes fixed below the iron shoes of the piles; as the sand was washed out of the way the pile was driven into position. The wooden piles are twelve inches square, and, placed end to end, would measure a hundred miles.



THE WEAVER SLUICES, MANCHESTER SHIP CANAL.

This timber-pile embankment is itself more than a mile long. At Runcorn there is a huge wall of concrete blocks, over 4,000 feet long, forty feet high, and from sixteen to twenty-two feet wide. You can imagine the time and the amount of material required for work of this kind.

At this end of the canal, too, are all the locks in which the ships are raised the necessary sixty feet. There are five sets of them, the set nearest the sea having three, and the others two, lock-basins. In each set one of the locks is 600 feet long and sixty-five feet wide, for the largest ships; the others are smaller. As water escapes into the sea every time the locks are used, it would be absurd to use the largest lock for boats that can lie in the smaller ones, but even they are 350 feet long and fifty feet wide. The lock gates are of greenheart, the wood of a large tree which grows in British Guiana. They are enormously strong and heavy, a single pair weighing 500 tons, and some of the logs which were imported for their manufacture were twenty-two inches square and sixty feet long. The main body of the canal is 150 feet wide at the bottom, and twenty-six feet deep, so that a ship of 10,000 tons burden can pass through it with ease and safety.

But the locks did not provide the greatest difficulty in the construction. Between Runcorn and Manchester there were valleys and low hills to be crossed. Some of the cuttings are sixty feet deep. Daily the stillness was broken by the sound of picks and shovels, and the hoarse roars of the explosions by which the rock was rent in pieces. Week after week, month after month, great steam navvies scooped up thousands of tons of material and loaded it into trucks which tipped it into the hollows in the path. Ten million tons of sandstone, and thirty

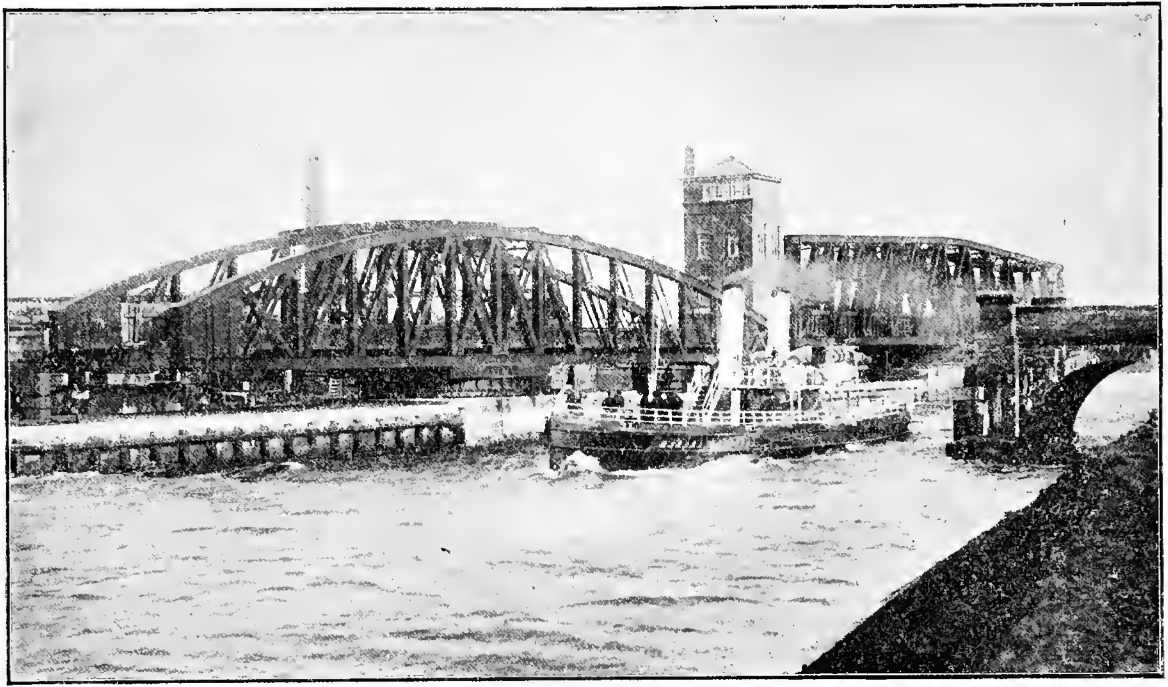


*Photo by* *Frith.*

BARTON SWING BRIDGE.

million tons of clay, shale, and sand were carved out of the ditch the water was to occupy.

The most wonderful work in the whole length is the Barton Swing Bridge. Here the Ship Canal passes underneath the aqueduct of the Bridgewater Canal, and as this was, as you know, only thirty-nine feet above the Irwell, the desired height could not be obtained, and it would have proved an obstacle to shipping. The difficulty was overcome by building in the lower canal a large pier of masonry, and mounting on this an enormous tank, 234 feet long, which forms ordinarily part of the Bridgewater Canal. The ends of the canal and of the tank can all four be closed by gates, so that the tank can be swung round with its length pointing up and down the Ship Canal, leaving a gap through which ships can pass. It is a curious sight to see this huge tank up in the air, containing perhaps a barge with its horse and man in charge. Brindley did some great things, but it may be doubted whether any of his work was so daring as this.

The canal was opened in 1894. Its length is more than thirty-five miles, and the cost, instead of being £8,000,000, was £15,168,000, or more than £400,000 per mile—that is, twice the cost per mile of the Suez Canal. Only a part of this was spent upon construction. Very large sums had to be paid to landowners, and two other cana's had to be bought up at a cost of £1,750,000.

Was the expenditure justified, do you think? One would say so; for, while the trade of Liverpool has continually increased, and, therefore, has not seriously suffered, in twenty years Manchester has risen to be the fourth port in the kingdom.

Manchester people are not only proud of their canal, but are bent on making it a success. On the hoardings,

on the tramcars, along the railway lines, are the magic words: "Manchester Goods for Manchester Docks," by which every citizen and trader is to be impressed with the importance of using the canal as a means of transport.

## CHAPTER XX.

### Joining the Oceans at Panama.

WE are going to consider now, not the longest canal in the world, nor the one that climbs over the loftiest hills, but the one that took the longest time to construct, killed the most men, cost the most money, and spread more ruin and desolation than any other great engineering undertaking of modern times. The waterway recently completed by the American Government across the Isthmus of Panama is one of the greatest engineering achievements of the world. It forms a new highway to the East, and will do for the commerce of the Western States of America what the Suez Canal has done for that of Europe. Not only will it be of incalculable benefit to American commerce, but it will probably also be used regularly by the shipping of the whole world, for it renders unnecessary the difficult and dangerous voyage round Cape Horn, where so many ships have been wrecked and so many men have lost their lives.

The idea of a passage through the narrow strip of land which Nature had thrown across the path of the circumnavigator dates almost from the days of Columbus; at all events, from the time of those later explorers who actually reached the mainland—for Columbus went no farther than the West Indies. But no serious thought was given to the matter until de Lesseps, flushed with

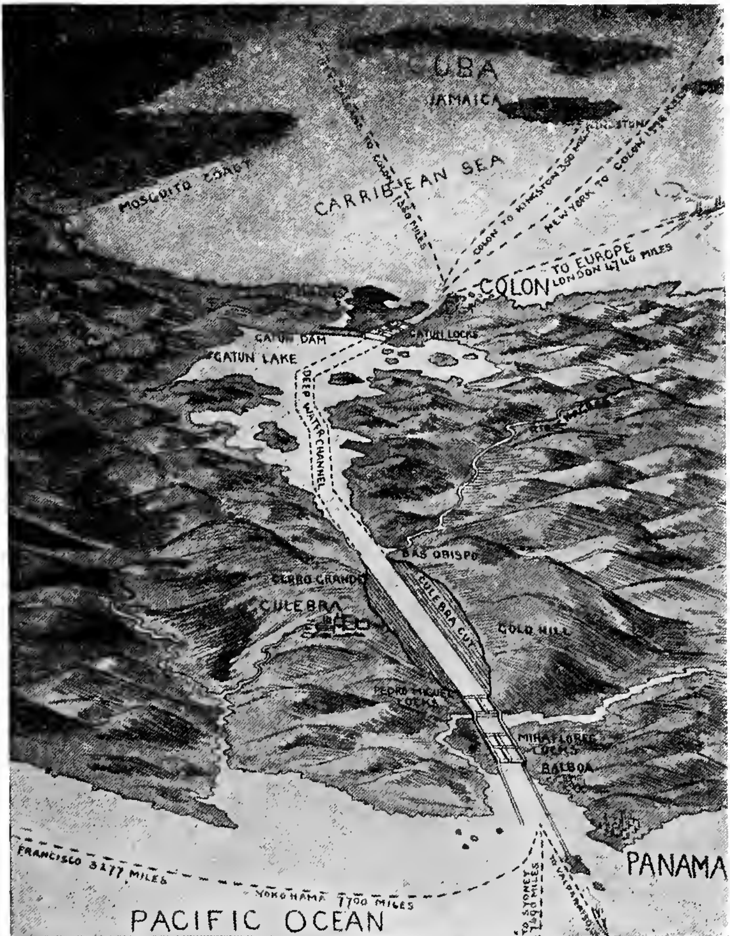
his victory in severing the connection between Asia and Africa, turned his attention to the Western Hemisphere. About 1880 he formed a company, with a capital of £16,000,000, in which 200,000 people took shares, to carve a passage from the Atlantic to the Pacific.

The Isthmus of Panama is not flat like the Isthmus of Suez, for the Cordilleras, part of the chain of mountains that forms a sort of western rampart to the continent of America, run through it near the Pacific shore. At the point where the line chosen for the canal crosses them, they fall a little, so that the summit is not more than 500 feet high; but to cut a sea-level canal, as de Lesseps intended, through this obstacle, was a tremendous undertaking—far greater, in fact, than anything that had been attempted in the world before.

Of the difficulty of making that deep trench through the mountain the great French engineer was fully aware; but there were two other difficulties which he found out only after the work had commenced. One of these was pestilence, the other flood. In the hot, moist, low-lying lands of the Tropics, yellow fever and malaria are terribly common, and the men employed in the work died in hundreds.

Again, the Chagres River, which is at times a mere trickling brook, at others is a roaring torrent which overflows its banks and spreads destruction over the valley. Time after time the water swept away tools and machines, broke down embankments, and filled up the trenches which had been dug out at so much labour and so great a cost. At Gamboa the sea-level canal was seventy feet lower than the river, and the dam by means of which it was proposed to divert the stream was far too weak for the purpose.

In seven years the expenditure amounted to £50,000,000




THE PANAMA CANAL.

or three times the capital, and de Lesseps realised that a sea-level canal was too vast an undertaking for the forces at his command. He immediately prepared plans for a canal with locks, and made a fresh effort; but fever, flood, and the mismanagement and dishonesty of some of the company's officials were too much for him, and he gave up the task in despair. Within eight years, thousands of men had lost their lives, £66,000,000 had been spent, and many thousands of people who had invested their money had been ruined. It was the most disastrous failure the world had ever known.

The work was not allowed to stop entirely. Sooner or later, that narrow strip of fever-haunted land had to be divided; sooner or later a water-passage from the Atlantic to the Pacific had to be made. A new Company was formed, the machinery was kept in order, and a little work was done. During the next fourteen years many discussions took place as to the best way to overcome the difficulties. In 1904, the United States Government stepped in.

Four years before, war had broken out in the West Indies between the United States and Spain, and the former country realised to the full the disadvantage of the long voyage from west to east round South America. The importance of having a canal across the Isthmus, in time of peace and in time of war, was too great to allow anything to stand in the way. The Government bought up for £2,000,000 the Company which had been scratching at the earth for fourteen years; they purchased for £2,000,000 a strip of land ten miles wide along the site of the canal; and they set to work with an energy, a foresight, and a determination that were bound to succeed.

The first step was to render the district healthy enough

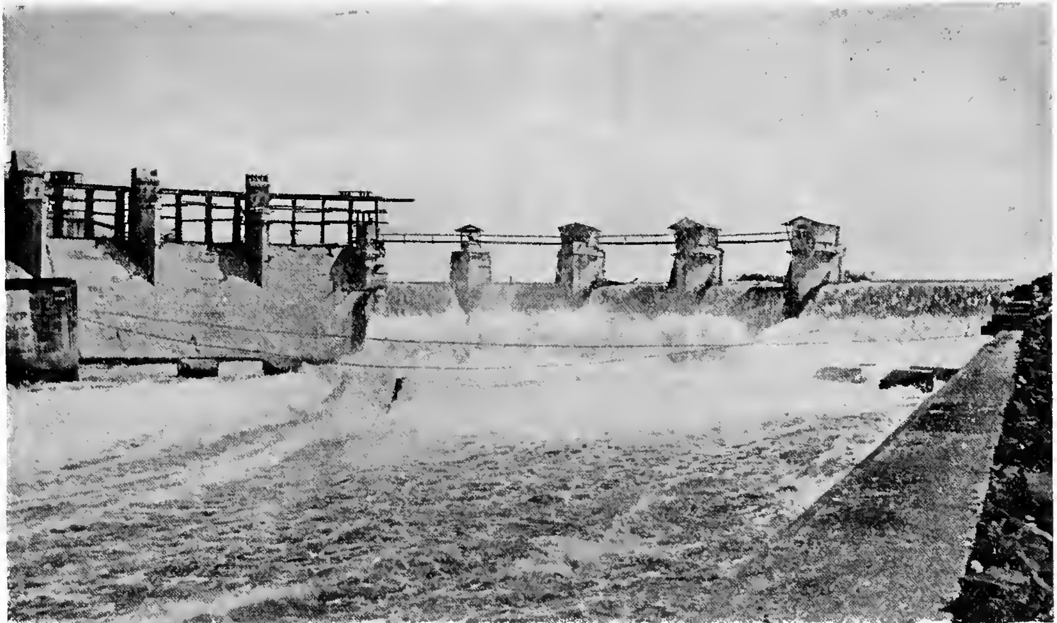


*Photo by* *International Publication Co.*

VIEW OF THE GATUN DAM SPILLWAY.

to live in. The French had thought that the sickness was due to the vapours that rose from the swamps when the heat of the day was over; but Major Ronald Ross of the Indian Medical Service had discovered that yellow fever and malaria were due to the bites of two varieties of mosquito. These little insects, which are a terrible scourge in the Tropics, breed in pools of water, and the best method of destroying them is to sprinkle petroleum in all places where they are likely to be found.

Petroleum was, therefore, laid all over the district in pipes, much in the same way as water is laid through the streets of towns in our country. At intervals, there were stand-pipes and taps from which tanks on wheels could be filled. Every day these tanks travelled up and down the land on each side of the canal, and every pool that might hide a mosquito was drenched with the liquid. The land was drained, the hollows were filled up, and the country was made a happy one for man, if not for the little insects which were so malignant.

But this was not the only precaution taken. The doors and windows of the houses were covered with copper gauze, so that while light and fresh air could enter, stray mosquitoes were kept out. For the time being, the whole population was in the hands of the doctors, who were keeping a sharp look-out for all kinds of disease. Hospitals and schools were built, and wholesome places of amusement provided. Never had the health and comfort of any group of people been so carefully and thoroughly considered and secured.

Having put an end to the mosquito through their medical staff, the Panama Canal Commission next turned their engineer on to the Chagres River. They decided that the canal should pass partly through and partly over the Cordillera Range, at a height of eighty-five feet

Photo by International Publication Co

THE FAMOUS CULEBRA CUT IN THE PANAMA CANAL.

above sea-level. Moreover, they determined to use the river to supply water to the canal. This was "taming" it with a vengeance. At Gatun, about seven miles from Colon, a huge dam was then thrown across the valley. What do you think of a great wall of earth and masonry 3,000 yards long and nearly 700 yards wide at the base? From the bottom it tapers upwards, until at the water level, eighty-five feet above the sea, it is 120 yards thick. Still tapering, it rises to 115 feet, where it forms a roadway more than thirty yards wide.

At one end of the dam is a spillway 100 yards wide and 400 yards long, which will allow 140,000 cubic feet of water to flow over it per second; and by the use of sluices the escape of water can be regulated so as to keep the level at the regulation eighty-five feet. In the old days the river has been known to rise thirty-five feet in twenty-four hours. The huge lake at Gatun has an area of 164 square miles, and the heaviest rainfall which has ever been known in the district would not raise the level by more than two and a half feet in the same time.

But this is not all the river is to be forced to do. A portion of the overflow from the lake is used to turn turbines, about which you will learn something later on, and thus produces all the electricity required for lighting and working the machinery of the canal from end to end. The treacherous and baneful stream has been made not only harmless but even useful.

The third big problem was the Culebra Cut. This is nine miles long, and for eight miles of the distance the depth varies from 100 to 320 feet. An easy slope has to be given to the sides to prevent their falling in, so at its deepest part the cut is 600 feet wide at the top, falling in wide terraces to about 300 feet at the bottom. Even then there has been an enormous amount of trouble owing

to land slides, and about 10,000,000 tons of material have had to be removed from this cause alone.

The French had excavated 85,000,000 cubic yards, and left the Americans twice as much more to remove. The rock was blasted out with huge charges of explosives, sometimes as much being used as 500,000 lb. in a month. Then the steam shovels came along and scooped up great mouthfuls of stones and earth which they tipped into the waiting trucks. These were drawn away to the spot where the dam was being made, and were there emptied by a most ingenious contrivance called a " Lidgerwood Unloader." When the train had reached the correct position, the ends of the trucks were let down, so as to convert them into a continuous trough. A huge plough was then drawn through the whole length of them from the back, by means of a wire rope and hauling-engine in the front part of the train. Is not that a great improvement on the method of shunting the trucks into position and emptying them singly ?

If you follow the canal from Colon, where the channel starts a mile outside the harbour, the first stretch of eight miles to Gatun is a level passage 500 feet wide. It then rises eighty-five feet by three pairs of locks to Gatun Lake, which it crosses in a channel not less than 1,000 feet in width. As it leaves the lake and approaches the Culebra Cut, it narrows down to 300 feet, and then opens out to 500 feet at Pedro Miguel, where there is a single lock with a fall of thirty-one feet. A mile below this is a pair of locks at Miraflores which bring the canal down to the sea-level, and from which the channel is dredged out for three miles to the deep water of the Pacific.

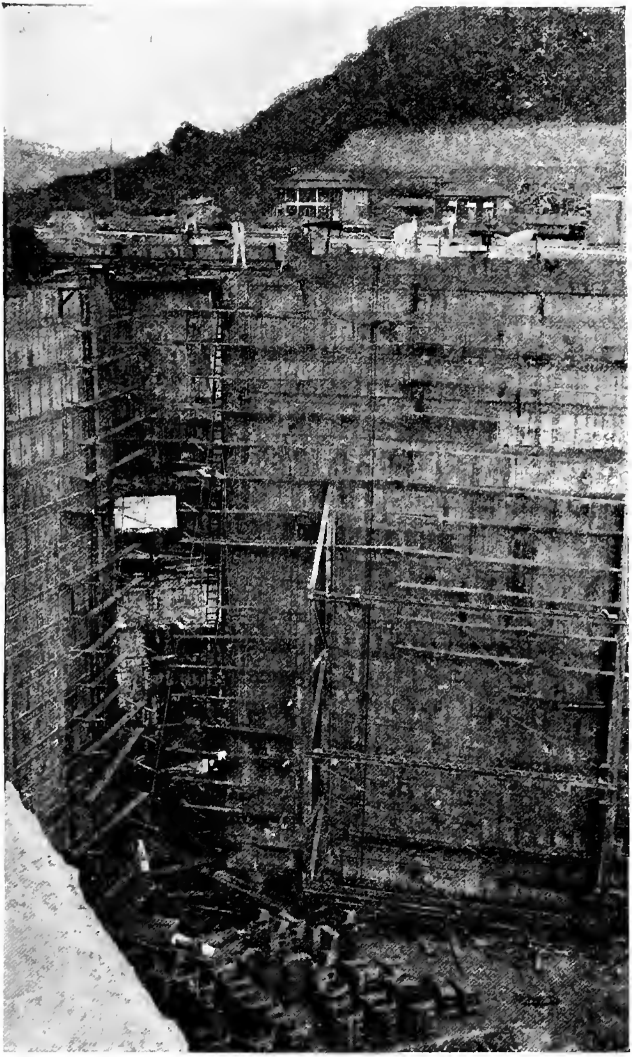
Every pair of these locks is an achievement in itself. They are 1,000 feet long and 100 feet wide, enclosed and

separated by concrete walls eighty feet high and sixty feet wide. The moulds in which these walls were cast, were built up by hand, but the concrete was mixed and poured by machinery. A man standing on a platform so that he could see what was necessary, pulled over a lever, and measured quantities of cement, sand, small stone, and water were delivered into an iron vessel. With the movement of another lever these were stirred and mixed, and at a third movement they were shot out into their place on the wall.

The machinery for opening and closing the gates and sluices is contained in the dividing wall, in which special chambers were built for the purpose. And powerful machinery it must be, to open and close gates which are seventy feet high and more than sixty feet wide. If these were damaged the cost and trouble of replacing them would be very great ; so it may be interesting to notice what steps have been taken to prevent accidents.

In the first place, ships are not allowed to proceed under their own steam. They are taken in charge by four electric locomotives, two in the front, and two behind, two being on each bank of the canal. Each pair of gates is duplicated, so that if there is damage done to one pair, another can be brought into use. Then, near each pair of gates is a kind of bridge, which can be swung across the canal; from this a sliding gate capable of holding back the water can be lowered. And, as if this were not sufficient, there is a heavy chain lying across the canal bottom in front of each pair of gates ; and, if a vessel is proceeding too rapidly, this chain can be drawn up across her bows, so as to stop her before she reaches the gates.

The whole canal is marvellous in its size, in its completeness, and in the enormous power which it represents.



VIEW OF A STEEL LOCK-GATE AT PEDRO MIGUEL, PANAMA CANAL.

The largest ship that has ever been built can enter its locks and be raised steadily at the rate of two feet per second, for over thirty feet at a time ; and in that way it can take a leap eighty-five feet high and over fifty-six miles long, from Ocean to Ocean. The dream of the early explorers has come true ; within the last fifty years man has carved out two deep grooves between continents, so that now he can girdle the earth without having to brave the storms and dangers of the northern or the southern seas.

And now we must leave canals, though there are scores of others that would be interesting, either from the difficulties met with in their construction, or from the purpose they serve. By their construction and use, man has improved upon Nature, which provided him with fitful and capricious rivers. These he has replaced by placid waters without current and without shoals to interfere with his navigation ; free, too, from that fierceness of temper that converts the river into a roaring torrent, which leaves death and desolation scattered in its track.

# SECTION V

## THE POWER OF FALLING WATER.

### CHAPTER XXI.

#### Interest from the Bank of Nature.

HAVE you ever watched a swiftly flowing stream, and thought what power was hidden in its silent depths? Have you listened to the roar of a great waterfall, and felt what labour it would save if it could be harnessed? Their energy is spent in wearing down the ground in which they are confined, tearing off fragments and carrying them away to the sea.

The power of a waterfall or river is only the power of the sun, offered to man at secondhand. For the sun, shining on the earth and warming the air, has enabled the latter to take up moisture, which the winds blowing over the land deposit as rain. Some of the rain falls on low ground, and some on high, but both portions begin to run back to the wide seas which were their original home.

Wind and water were the first agents man used to relieve himself of manual labour. And they brought him more than mere relief. They enabled him to perform tasks which, in the absence of mechanical power, he would never have been so daring as to attempt. And, by bringing him success, they increased his confidence, stimulated his ambition, and helped him to take those early steps on the ladder whereby he has climbed from the level of the beasts of the field to his present plane of civilisation.

Before we proceed to examine the way in which water is made to yield up its latent power, it will be as well to point out that the use of water-power is the prevention of waste in the kingdom of Nature. The energy of the water which is utilised is that which is on its way to the sea. Whatever useful purpose it could naturally serve on the land has been accomplished, and it can do no more than carve still deeper the channel through which it flows.

As the process by which water is continuously being raised from a lower to a higher level is a natural one, arising from the influence of the sun, this source of power is always available. Man cannot use it up faster than it is supplied, and he cannot exhaust the store. True, he may harness every available stream or waterfall, but, when he has done that, he can rely upon a regular supply, varying little from year to year. Coal and petroleum are present in the earth's crust in limited amount—vast this amount may be, but still it is limited. They were formed in past ages when the conditions were not the same as they are now, and, so far as we know, neither coal nor oil is being formed at the present time—at any rate, not in anything like the quantity that man requires. So, while the engineer who uses steam is drawing his capital from the Bank of Nature, the engineer who uses the power of falling water is merely drawing the interest.

The rate at which coal and oil are being used up is so great that a few hundred years more will see the end of the store in Great Britain at any rate. This may seem a great length of time to an individual, but it is a small span in the life of a nation, and an almost immeasurably small fraction of the time man has lived on the earth. In the last two hundred years he has been plundering the store-house of Nature,

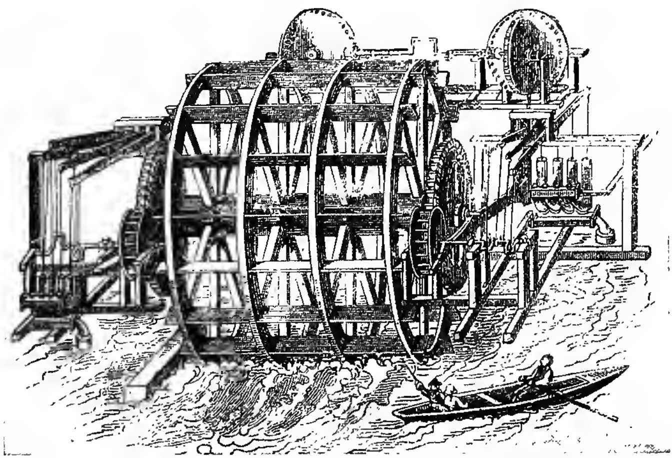
and the riches he has acquired have enabled him to make greater material progress in that period than in all the previous history of the world. Is this progress, then, to come to a standstill within a period less than one-third of that which has elapsed since William the Norman landed on the south coast? Or will there be some new discovery that will replace coal? Engineers and manufacturers are fully aware of the need for saving fuel. The methods they are adopting are described in *The Mastery of Fire.* In the meantime water is being utilised more and more in every country in the world. For every unit of horse-power produced by water per annum, no less than twelve tons of coal are saved, and, as there is to-day probably 10,000,000 horse-power produced in this way man has already succeeded in saving 120,000,000 tons of coal a year.

## CHAPTER XXII.

### Water Wheels and Turbines.

THE methods of obtaining power from water vary greatly with the conditions. Thus a wheel with blades on the edge can be mounted over a swiftly moving stream at such a height that the current presses against the lower blades. The chief disadvantage of this arrangement is that the level of the water may vary throughout the year, so that, if the axis is fixed, the blades may either stand above the surface, or else be buried so deeply that the upper portion of the water hampers the movement of the wheel. An ingenious method of overcoming this defect has sometimes been employed. The wheel is mounted on a raft which is moored in position and rises and falls with the level of the stream. There was

formerly a wheel of this kind under one of the arches of Old London Bridge, the power obtained being used for pumping. Another arrangement, where a small fall can be obtained, is to fit buckets or boxes on the wheel instead of blades. The water then meets the wheel on a level with the axle, and fills the buckets one after another; in falling, these cause the wheel to turn, and are emptied



A WATER-WHEEL UNDER OLD LONDON BRIDGE.

out at the bottom. Both these are called "undershot" wheels, because the water which does the work passes underneath.

A more common form is an "overshot" wheel. In this case, a fall from the upper reach to the lower reach (or tail-race) of rather more than the full diameter of the wheel is required; so that, for a given fall, a larger undershot than overshot wheel can be used. It is clear

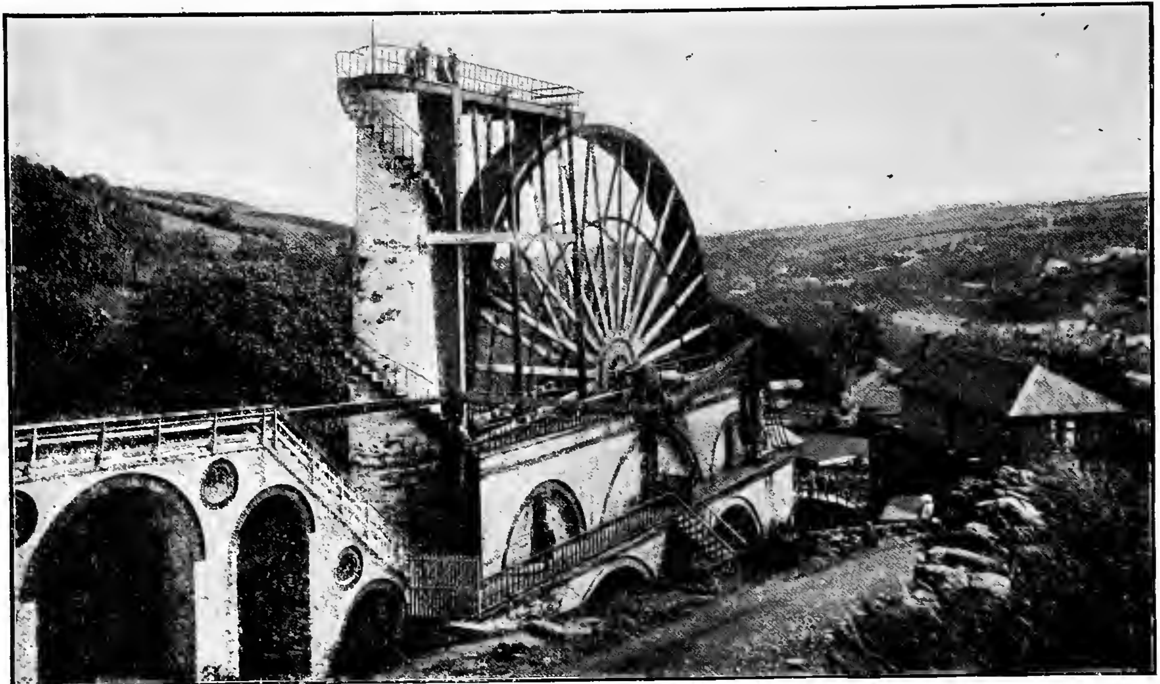


*Photo by* *Frith.*

LAXEY WHEEL.

that, for a given height of fall, the larger wheel will produce the larger amount of power, for the weight of the water will act at a greater distance from the axle. There is a very large overshot wheel at Laxey, in the Isle of Man. It is just over seventy-two feet in diameter, and produces 150 horse-power, which is employed in pumping 250 gallons of water per minute from a lead

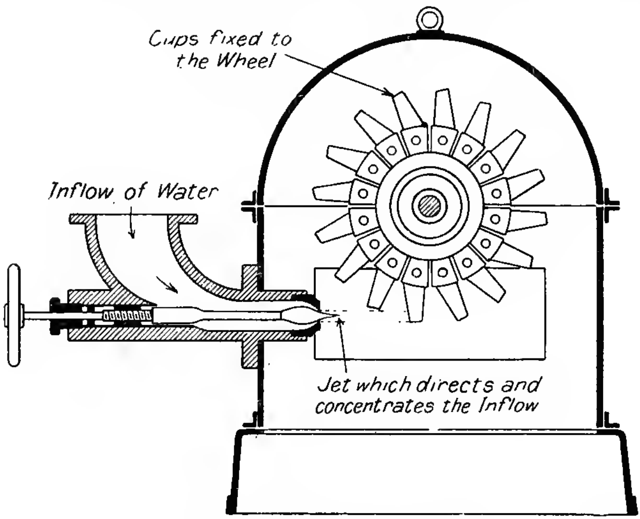



DIAGRAM OF A PELTON WHEEL.

mine nearly 1,200 feet deep. Fancy a wheel with a diameter twice as great as the height of a three-storied house !

The old waterwheels—constructed generally in whole or in part of wood—were clumsy, creaking machines and, though useful in their way, gave very little power for their size. As man gained greater skill in working with iron and steel, he relied more and more on these materials.

With them he is able to make machines, to work by water, so small that you can lift them with one hand, and so large that you have to climb about them with ladders. And in every case they are far more powerful than an ordinary water-wheel of equal size.

These machines are made usually of only two types, Pelton Wheels and Turbines. The Pelton Wheel, as will be seen from the illustration, is simply a wheel with a number of "cups" or "buckets" round the rim. It is driven by a jet of water at high pressure which is directed upon the buckets when they are in their lowest position. There is a very interesting relation between the velocity of the jet and the speed of the wheel and buckets which is well worth a short explanation.

The velocity which water acquires in falling or flowing from a high to a lower level depends upon the height, and is given by the formula—

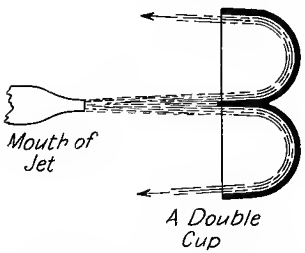
$$V^2 = 2gh,$$

where $v$ is the velocity in feet per second, $h$ the height in feet, and $g$ the constant of gravity, which has approximately the value thirty-two. Thus, if water flows through a pipe from a reservoir 100 feet above, the velocity will be—$\sqrt{2 \times 32 \times 100}$, *i.e.*, eighty feet a second. Actually the velocity will be a little less, owing to friction in the pipe.

Suppose water with this velocity is being used to drive a Pelton Wheel. If the wheel is turning so fast that the buckets have the same velocity as the water, the water will exert no force upon them at all. They will run away just as fast as the water approaches them, and the water will be doing no work at all. Next consider the wheel to be held fast. Owing to the curved shape of the buckets, the water will curl round and be flung back

in the opposite direction, with very nearly its original velocity. But moving water can always do work, so the work which the water could have done is again wasted. It is evident that most work will be got out of the water by robbing it of all its velocity. In other words, the buckets must move just so fast that the water neither follows them up, nor is flung back, but simply drops out below. This condition is fulfilled when the buckets are moving with half the velocity of the water in the jet.

You will easily see that the velocity of the water is fixed by the positions of the reservoir and of the wheel, and this fixes also the speed of the buckets. A low speed is obtained by a large wheel turning slowly and a high speed by a small wheel turning quickly; so that, with the same head of water, the engineer can choose his wheel to give a large or a small number of revolutions per minute as he requires.




SECTION OF A PELTON WHEEL.

You will notice that the buckets of a Pelton Wheel are really "double cups," with a sharp ridge down the middle. The jet strikes this ridge and is divided by it so that the two halves curl round in opposite directions. This avoids splashing and waste of power. The advantage was discovered by accident; the story shows the importance of careful observation, even in regard to machines and methods that have been used for many years.

Wheels with single cups were very largely used in connection with gold-mining on the Pacific Slope of North America. A mechanic, named Pelton, had a number of these wheels in his charge, and noticed one day

that one of the wheels had become displaced sideways, so that the water jet struck the edge instead of the middle of the cup. He saw that not only was there less splashing, but the wheel ran more rapidly in this position. So he constructed a wheel with divided cups, and found that his eyes had not deceived him. Ever since then, his name has been given to a wheel with cups of this kind.

Pelton Wheels are made so small as to give one-fifth of a horse-power, and so large as to give nearly 20,000 horse-power. But the largest wheel is not necessarily the most powerful, because the power depends on the force of the water jet. For this reason they are only useful when a large head of water is available, though the volume supplied by the pipe need not be very great. When a very large power is required, each wheel is supplied with two, or even three, jets ; and two wheels may be mounted on one shaft. The speed is governed in one of two ways. Either the jet is made with a joint, so that it can be bent downwards and thus miss the buckets, if the speed is too high ; or else the opening is closed by a needle-valve and conical plug inside the jet, which is pushed forward and closes the opening very gradually.

When the volume of water available is large, or the fall is low, the Pelton Wheel is replaced by a Turbine. Inside a casing is fitted a boss with large curved blades. Water enters the casing and is directed upon the blades by means of guides. In order to escape near the boss, the water presses upon the blades and causes the axle upon which the boss is mounted to spin round.

Turbines usually have a horizontal axis just the same as a Pelton Wheel, but if the fall is very low (and they will work with a head of three feet) vertical turbines are

used. The runner of a vertical turbine is rather more easily illustrated than that of a horizontal one, and the action of the water will be understood from the figure. The diagrams also show how both inward flow and outward flow turbines are fixed in position, and how the water is led into and away from them.

As a rule the turbine should be placed as low as possible in order to utilise the largest head; but if the tube leading to the tail-race is properly constructed and proportioned, the "pull" of the column below the turbine

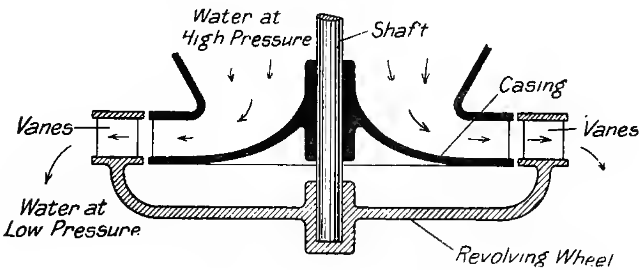
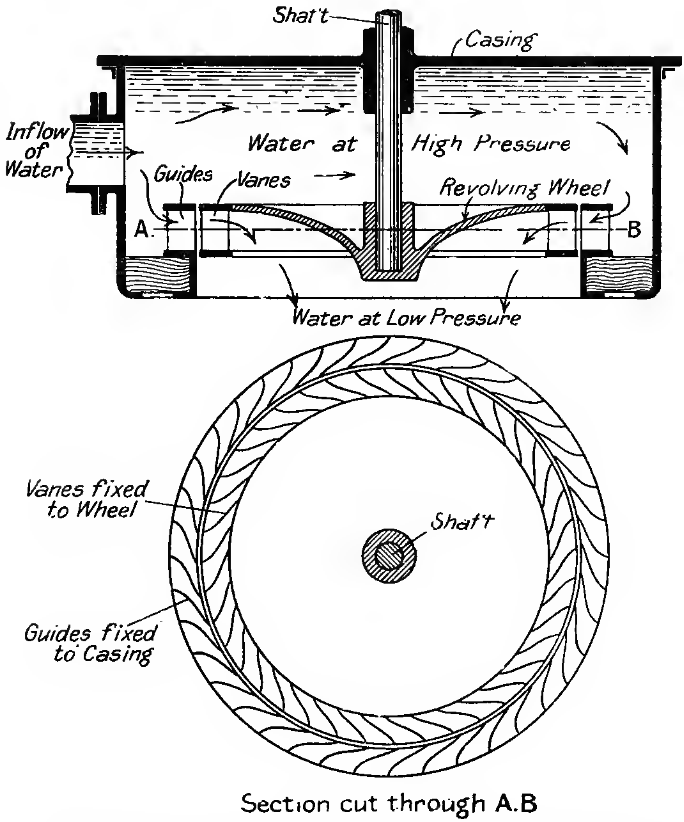



DIAGRAM OF AN OUTWARD FLOW TURBINE.

is also effective, because it tends to break away and form a vacuum below the moving blades.

In order to get as large a fall as possible, the water is sometimes led for miles across country in open channels or flumes, or in steel pipes. It crosses low ground on bridges, and is conveyed through mountains by tunnels, which in many cases add enormously to the cost of the works. Water power is cheap because the water costs nothing, but the works are generally very expensive. The most important condition is that there should be a constant supply. A number of water-power stations which take their water from rivers without any arrangements

for storage have to shut down in dry seasons—an irregularity which is disastrous in modern industry. So




DIAGRAMS OF A FRANCIS TURBINE (INWARD FLOW).

we shall find that, if no natural lake is available, one has to be formed by a dam, just as in the case of irrigation and the water supply of towns.

And now that you have some idea of the way in which water is utilised, let us set off on a tour round the world and look at some of the places where man is controlling the river and training the torrent to drive his factories and workshops in the twentieth century.

## CHAPTER XXIII.

### Levying Toll on Niagara.

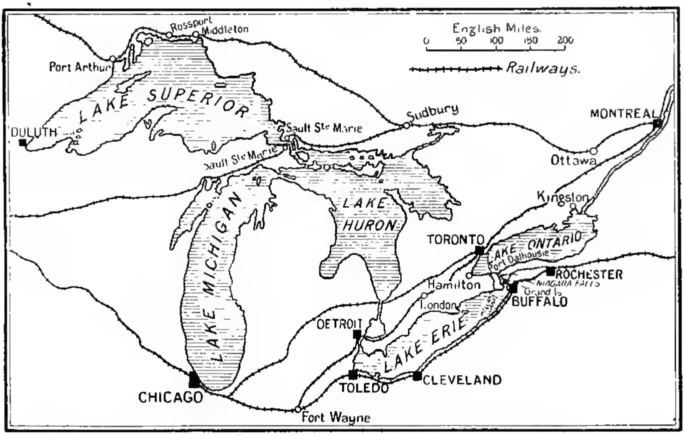
If ten people were asked to give the name of a famous waterfall, nine of them would say Niagara. For the Falls of Niagara are mentioned in every book on geography; they are visited by every tourist who goes to Canada and have shared in the publicity which has been given to the most widely advertised country in the British Empire. While not by any means the largest falls in the world, they are the nearest to civilisation; and they are grand enough to deserve all the admiration which has been bestowed upon them.

A glance at the map of North America reveals a group of large lakes which lie between the United States and Canada. A closer inspection shows that they are connected with one another by narrow streaks of water, but there is nothing to tell you whether they are all at the same level or not. As a matter of fact Lake Superior empties itself into Lake Huron by a stream studded with rapids, so that canals have been cut on each side to create waterways between the rich mines and farms on the northern shores of Superior and the manufacturing towns south of Lakes Michigan and Erie.

Between Lake Huron and Lakes Michigan and Erie there is very little difference of level, and the channels

are wide enough and deep enough to enable the surplus water to escape without excessive turbulence. But Lake Erie lies 326 feet above Lake Ontario, which is the source of the mighty river St. Lawrence, and the Niagara River has been called the spout through which Lake Erie discharges its waters into Lake Ontario.

The drop of 326 feet within thirty-six miles would give the Niagara River a swiftly flowing current in any




SKETCH MAP OF THE GREAT LAKES.

case; but the fact that the fall is 216 feet within two or three miles concentrates the available power within a very short distance. About half-a-mile above the Falls, the river is 3,400 feet across. At this point it is divided by Goat Island into two streams, one on the American side and one on the Canadian side. On coming abreast of the downstream end of Goat Island, the former leaps over a cliff 167 feet high and 1,000 feet wide, into the river below. The Canadian branch scrambles in a series

of rapids about eight feet lower and then pours over a horseshoe-shaped lip, 2,600 feet long, in a magnificent sheet of water half-hidden at its lower end by the spray.

It has been estimated that a quarter of a million cubic feet of water pass over the falls in each second, or almost before you can say "Jack Robinson." Look at the clock for a minute, and see if you can realise that in such a short space of time fifteen million cubic feet of water have swept with a rush and a roar through the gorge of Niagara. If you are good at figures, you can easily find that this amounts to about a cubic mile a week, and if this seems less imposing than when given in cubic feet, convert it into units of weight, and show that it amounts to 25,000,000 tons an hour; 600,000,000 tons a day; 4,200,000,000 tons a week; or over 200,000,000,000 tons a year!

If the whole of this stupendous volume of water could be harnessed it would produce about 5,000,000 horse-power, and as for each horse-power twelve tons of coal per annum would be required, 60,000,000 tons of coal a year would be saved. When this power is converted into electricity it can easily be transmitted 250 miles, and possibly in time 500 miles will not be too great a distance. A circle drawn with Niagara as centre, and 500 miles as radius, includes the chief manufacturing population of the United States and Canada, and in this vast area the total amount of power used is rather less than 15,000,000 horse-power—at least, that was the amount estimated in 1910. Of this, Niagara could not supply more than one-third, a result which shows at once both the present importance of coal and the future importance of water-power.

But Niagara is not supplying 5,000,000 horse-power, nor anything like it. The five Companies which have

laid down turbines to sip its waters are not taking more than ten per cent. of it; and yet, as we shall see, they have altered the face of the land, and have created busy manufacturing centres where twenty-five years ago there were silence and solitude. Whether this is an advantage or not you can debate with your friends.

When it was first decided, soon after 1870, to make use of this enormous natural source of power, the project was not undertaken lightly. The whole question was submitted in 1886 to a committee of famous scientific men, on which England, France, Italy, and America were represented. The plan recommended was to sink deep pits by the side of the river above the Falls; to lead the water down pipes suspended in the pits, and fitted with turbines at their lower ends; and to convey the escaping water through tunnels into the lower part of the river.

The water is led to the top of the pits by short canals into reservoirs at the side of the stream. From there it flows down pipes—some of which are more than ten feet in diameter—to the turbines, which are 170 feet below the ground level. One of the tunnels through which the water escapes from the turbines is twenty-one feet wide, nearly nineteen feet high and more than one and three-quarter miles long. From the pits and tunnels nearly 400,000 tons of rock were taken, and the construction of the tunnel alone occupied 1,000 men for three years. What do you think they were doing in that time? Well, not only making the tunnel, but also lining it with 16,000,000 bricks!

The method which has just been described was adopted by two Companies, "The Niagara Falls Power Co." and "The Niagara Falls Canadian Power Co." Together they develop about 220,000 horse-power, which is used for producing electricity, and supplying in this way scores

of towns and villages in the neighbourhood. One of the first towns to derive benefit from the installation was Buffalo, at the Lake Erie end of the river, where, though

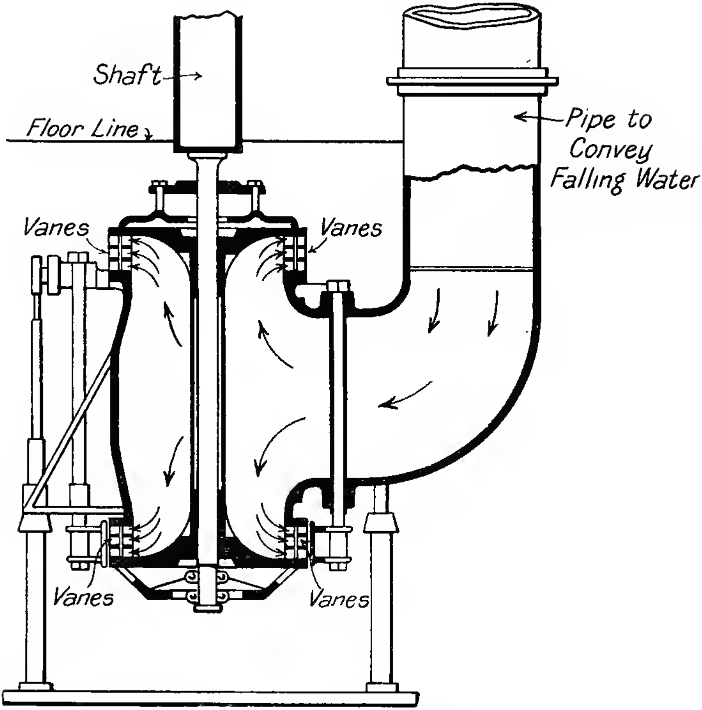



DIAGRAM OF THE TURBINES USED BY THE NIAGARA FALLS POWER CO.

coal was only about 6s. a ton, electrical power was cheaper—in fact, only about one-sixteenth of a penny per horse-power per hour.

"The Niagara Falls Hydraulic Power and Manufacturing Co," on the American side, has its power-house

situated at the base of the cliff below the Falls. The water is led from the upper river in a long, open canal to the top of the cliff. Here it flows down a long steel tube, or "penstock," which makes a sharp bend at the bottom, where it runs into the power-house. In this way, the cost of sinking pits and driving tunnels was avoided; so also was that of the long steel shafts leading from the turbines below to the dynamos above, which needed to be supported at intervals in their 180 feet of length.

The largest and most recent of the water-power stations at Niagara is that of "The Ontario Power Co." The water is taken on the Canadian side, just above the rapids, and led through two enormous steel and concrete tubes, or "conduits," about eighteen feet in diameter, just below the surface of the Victoria Park, which occupies the high ground above and below the Falls. The length of these tubes is about a mile and a quarter, and, as you may imagine the difficulty of stopping water in them when it is in movement, you will be interested to hear how it has been overcome.

The conduits terminate in a huge tank, seventy-five feet in diameter, from which there is an overflow near the top. The penstocks leading to the power-house branch off from the undersides of the conduits just before they reach the "surge tank," as it is called. They are nine feet in diameter, and are fitted with valves, opened and closed by electric motors. When the water is cut off from the turbines, it "surges" up into the tank until its energy has been spent.

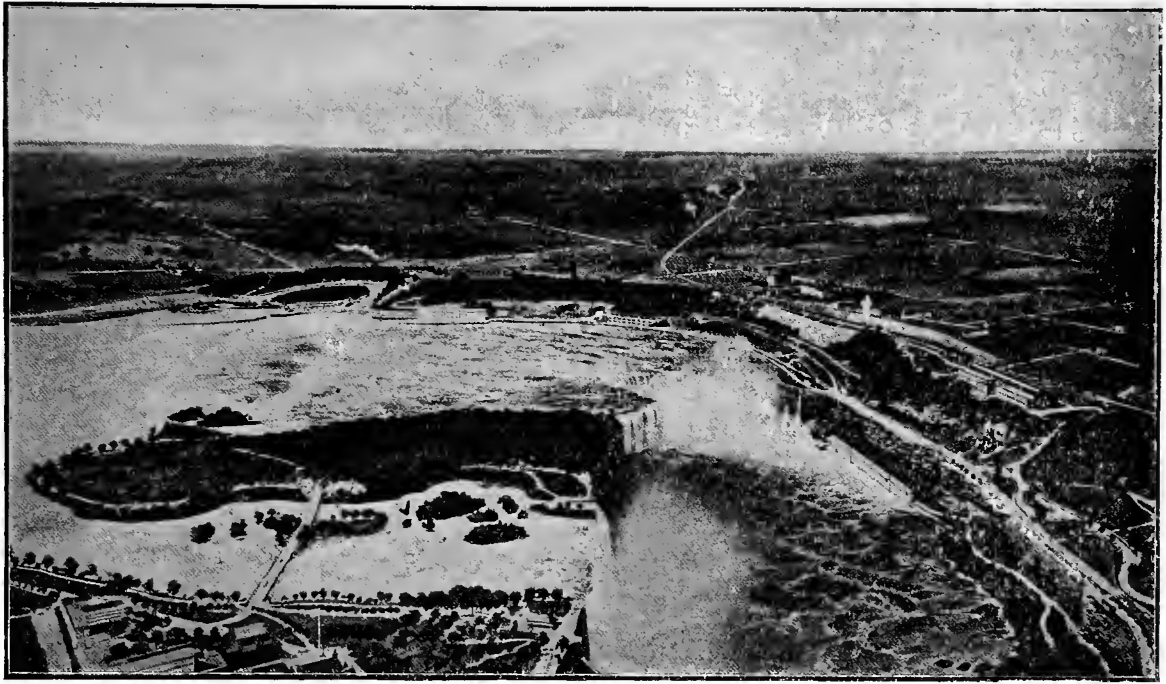
If some such plan were not adopted, a sudden stoppage of the water by closing the valves would cause such a rise of pressure that the conduits might burst. But the surge tank serves an additional purpose. When the

valves are opened and the water begins to run through, it takes some time for the message, "More Water Needed," to reach the "intake" a mile and a quarter away. So, until the long column of water begins to move, the surge tank supplies what is required.

Another interesting part of the scheme is the intake works. The neighbourhood of the great lakes has a severe winter, and the river is occasionally blocked with ice. Moreover, every swiftly flowing river carries down branches of trees and other materials, which, as well as the ice, would be liable to choke the tubes and stop the turbines. Every precaution, therefore, has to be taken to prevent anything but water from entering the conduits.

This necessity led to the construction of elaborate works at the point above the rapids where the water is taken. A huge wall was built out from the bank nearly parallel with the main current, continuous along the top, but with twenty-five submerged arches through which water could pass from the bottom of the river. From the downstream end of this wall another wall was built, solid, but with its top just below the surface. The floating ice and other material were thus held back by the first wall, while surplus water could escape over the lower one. The enclosure is called a "forebay." But in a turbulent stream like the Niagara River one cannot be certain that all the suspended matter will be at the top; so, before passing to the conduits, the water flows into an inner forebay, beneath a concrete curtain which hangs down five feet below the surface. The entrances to the conduits are again protected by huge iron gratings, and, lest these should become frozen over, steam boilers are provided to melt any ice that forms.

This company produces about 200,000 horse-power and distributes it in the form of electricity to over a hundred



*By permission of* *The Ontario Power Co.*

NIAGARA FALLS, SHOWING AN ELECTRIC POWER STATION.

cities, towns and villages in Ontario and the State of New York. It is used for public and private lighting, manufactures, tramways and electric railways. North, south, east and west, the electric cables are carried on steel towers sixty feet high, reaching to Windsor in Ontario, 220 miles away, and performing many services in Syracuse, 160 miles away, in New York State.

Since the first works were established about twenty years ago, the whole aspect of the country has changed. Manufacturing towns have sprung up ; a vast population has collected ; everywhere the lowing of cattle and the rattle of the reaper have been replaced by the hum of machinery and the tramp of busy men. Meantime, the food required by the workers has been wrung from the virgin soil in regions where power is scarce and man depends upon his good right arm and his trusty horse.

Niagara is not the only source of water-power in Canada. Its importance is due to the fact that it is one of very few sources of power near to the valley of the St. Lawrence, which was the first part of the Dominion to receive the overflow of population from European nations, and to New York State, which, by its care and foresight in conserving its waters, is the richest manufacturing state of the Union. Westward from the St. Lawrence is a vast plain, growing enormous crops of wheat, and so level as to encourage the construction of railways to convey the corn to market. In this great task of transporting food to the eastern workers, the lakes take no small share.

As the area of cultivation in Canada is extending westward, the importance of water, both for irrigation and for power, again arises. The Bow River, fed by the glaciers of the Rocky Mountains, flows through Southern

Alberta past Calgary, which has recently become well-known in consequence of the discovery of oil. At Horseshoe Falls, fifty miles west of the town, a dam was thrown across the river and a power house erected in 1911. So readily was the power taken up that within two years an extension of the works had to be undertaken.

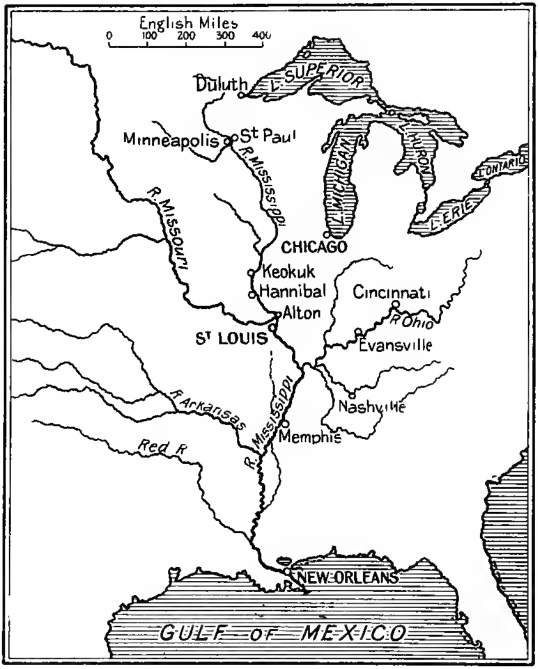
British Columbia, as you know, lies between the crests of the Rocky Mountains and the Pacific Coast, and includes the Cascade Range on its extreme west. The torrents which pour through the steep, narrow valleys have long been used to supply power to the saw-mills and mines, and in this region great wealth of running water lies. It is estimated that in the whole of Canada there is available more than 25,000,000 horse-power. Of this Quebec claims 17,000,000, Ontario 3,000,000, British Columbia 2,000,000, and Alberta 1,000,000 The present century will witness a succession of great schemes which will confer upon the descendants of the early settlers all the advantages possessed by the older civilisations. Factories will arise and towns will grow, competition will become keener between man and man, and greater demands will be made upon Mother Earth for the food that the factory worker does not produce for himself.

## CHAPTER XXIV.

### Harnessing the Mississippi.

No country in the world has so fully appreciated the advantages of water-power as the United States of America, and, for this, credit must be given to the daring and reckless miners of California and the Pacific Slope, whose work has been described in *The Mastery of Earth.*

The streams that have their birth among the crags and precipices of the Rocky and Cascade mountains, and the saw-like crests of the Sierra Nevada, are being tamed one by one. The waste water, hastening to the sea,




A MAP OF THE RIVER MISSISSIPPI.

is held up by dams and made to perform some useful work in its downward path. But to describe even a few of the examples of man's control over natural forces in this region would take up more space than can be spared, and we shall consider only how one of the largest rivers

in the world—a river with caprices that have been the despair of generations—has been brought into subjection.

The mighty Mississippi rises west of Lake Superior and flows southward for nearly 1,600 miles to the Gulf of Mexico. In the latter half of its length it includes also the waters of the Ohio and the Missouri, and winds across a level plain, which it visits every now and then with terrible floods. At these times the current scours out its banks and gives the officials of the United States Government plenty to do to maintain the channel. It is connected with Chicago (by canal) at the southern end of Lake Michigan, and it is navigable throughout its length, except at a few places, for vessels drawing nine feet of water.

The great lakes are, as you know, the centre of trade and transport for the continent of North America. Their coast-lines are dotted with the termini of the principal railways, and the Welland Canal enables ships of considerable size to pass from Lake Erie to Lake Ontario, and thence to the St. Lawrence and the sea. For nearly twenty years now, it has been possible to send ships from Manchester to Chicago, thus avoiding the trouble and expense of unloading and reloading.

From Chicago a canal runs to the upper reaches of the Mississippi, so that this great centre has also a clear waterway to the Gulf of Mexico. But the problem which the Americans have set themselves is to secure a clear fourteen feet of depth throughout the whole distance, and incidentally, to make use of the water as a source of power on the way. The credit for the scheme to be described belongs to one man, Mr. Cooper, who has promoted the company, raised a capital of £2,500,000, designed the works, and had them executed under his own supervision.

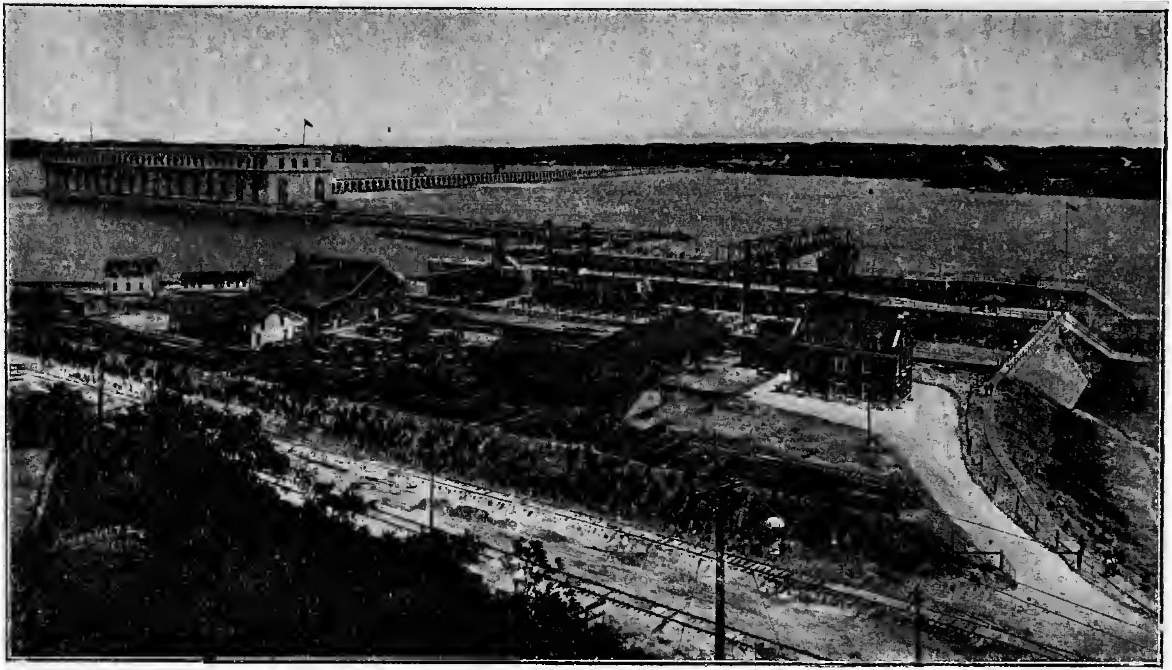
The first thing was to raise the ordinary level of the river; the spot chosen lies between Keokuk and Hannibal, about 140 miles above St. Louis. At this point the river is about a mile wide, and flows over a solid limestone bed between steep limestone banks. There was a good foundation, and a task that you would think of no great difficulty. But the Mississippi is not the sort of river to flow along peacefully while a barrier is being built across its channel; there are times when the water trickles along at the rate of 20,000 cubic feet a second, and there are other times when it comes down with a roar and a volume nearly twenty times as great.[1]

The illustration on page 159 shows you that the works consisted of a dam, running for 4,700 feet across the river, stopping a thousand feet short of the right bank. Below the opening thus formed was built a canal with locks, to allow boats to go up and down the river. The power-house forms one side of this canal which is protected, by a long pier, from the ice which comes down in the spring.

The dam was built of ferro-concrete, a portion at a time, the work being done inside a coffer-dam. Grooves were cut in the bed, the sides of the coffer-dam were lowered into these, made water-tight, banked up on the outside with earth and stones, and the water pumped out. The closing of the last opening was, as you may imagine, a difficult task, for the obstruction caused a difference in height of several feet on the upstream and downstream sides, and the water poured through the remaining space with tremendous power.

The coffer-dam for enabling the power-house to be built enclosed an area of thirty-five acres. In order to save expense, the sides were not carried up to the

[1] The flow of the Thames in flood is about 10,000 cubic feet a second.



*By courtesy of* *The Mississippi Power Co.*

THE WORKS ACROSS THE RIVER MISSISSIPPI.

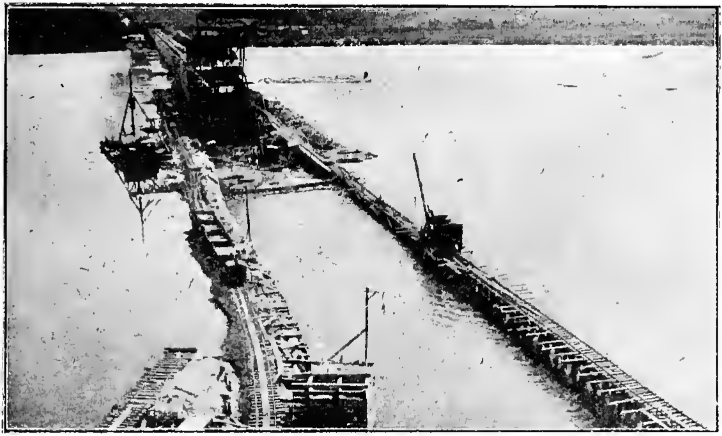
maximum flood level, and there was a consequent risk of the water breaking in. On one occasion the ice broke up suddenly and began to move down stream. The means of escape provided were too small, and the blocks from twenty-four to thirty inches thick, were piled up in a steep slope against the obstruction. Below the coffer-dam, also, the ice formed a barrage. Men were set to work to raise the coffer-dam. They carried it up four feet with earth and rock, but still the water rose; a foot higher than this, and the ice jam gave way.

The excitement was not yet over. The melting ice swelled the flood until the river rose another foot, and men were engaged for two weeks in fighting the waters by placing earth, rock, and sandbags on the outer surface at every point that showed weakness. Then "early one morning, a violent storm from the north, sweeping over the great expanse of water above the dam, drove the waves so high that they began to break over the north coffer-dam, the crest of which was an earth bank some two feet thick. The fifty men on guard were unable to place sandbags fast enough and the workmen at the camp were called out about 3 a.m. Working in the rain and wind and darkness, sometimes knee-deep in water, and with the river almost overtopping the work, they succeeded in protecting the face and filling up places washed by the waves." [1]

The coffer-dam stood, the power-house was built, and, when all the turbines have been installed, no less than 300,000 horse-power will be provided from a head of thirty feet of water. The reservoir extends for sixty miles up the river, and roads and railways have had to take a new direction. These changes may not be benefits, but let us look at the other side.

[1] *The Engineer.*

In the first place, 60,000 horse-power is supplied to the city of St. Louis, 140 miles away, for lighting and tramways, so the smoke of a central station, burning coal, will be rendered unnecessary. The coal-mines and factories of Alton, and the lighting and tramways of Keokuk, take another portion. Ten thousand horse-power goes to the Atlas Portland Cement Works at



*By courtesy of* *The Mississippi Power Co.*

A GENERAL VIEW OF THE COFFER DAM FROM THE IOWA SIDE.

Hull, and 2,000 horse-power to the Central Public Utilities Company, which supplies 125 cities, towns, and villages with electric current for tramways, railways, waterworks, drainage pumps, and other purposes. Keokuk itself, which is served by several railways, will in time become an important manufacturing centre.

So much for the United States, which is estimated to have available not less than 36,000,000 horse-power, of which only 6,000,000 is yet in service.

## CHAPTER XXV.

### The White "Coal" of Scandinavia.

NORWAY and Sweden are lands of lofty mountains, and deep valleys, carved out by the glaciers of former ages. The forest-clad slopes, the rich mines of iron ore, and the "harvest of the sea," have enabled the hardy race that inhabits the peninsula to contribute no small share to the trade and industry of the world. But the nature of the land renders transport difficult, and the short summers are not favourable to agriculture.

Of water there is plenty; nearly every valley has its torrent and waterfall, which, so long as they are not far from the coast, have attracted an annual army of tourists for many years. So long as a river was only of value for navigation, and a waterfall could only produce power "to be consumed on the premises," the mountain streams of Scandinavia were there to be looked at and not to be used. But as man found out new uses for electricity and grew more daring in transmitting larger quantities of it for many miles across country, Norway and Sweden found a use for rivers, and proceeded without delay to develop natural resources which had long lain idle.

During the last fifteen or twenty years, a change has been going on in both countries which has hardly been noticed, except by those who do business with them, or who make it their business to follow the trade returns of the world. The iron trade has received a new lease of life; the export of timber and the fisheries still go on; but, in addition, an export trade has arisen in materials manufactured in electric furnaces, driven by

the water that tumbles down the mountain sides in its haste to reach the sea.

In the Tellemarken District there are two lakes, one about 2,000 feet above the other, connected by a river which leaps over a huge cliff in its course. The water

*By courtesy of* *"Engineering."*

GENERAL VIEW OF THE RJUKAN PIPE LINE.

of the upper lake, Lake Mosvand, has been held up by a dam, and is led through ten steel pipes, each five feet in diameter, to a power house at Rjukan, over 900 feet below, where it produces 140,000 horse-power. From this it is led to another power house, 900 feet lower still, where it is used over again, and produces 115,000

horse-power, before it flows into the River Maane to be carried to the Lake Tinnsjo.

Below Lake Tinnsjo is another fall, where power-houses have been built at Lienfos and Svaelgos, levying further toll before the water flows into the Baltic Sea. At these lower stations another 60,000 horse-power is obtained. When the whole scheme is completed, no less than 540,000 horse-power will be available. This is very nearly as much as is produced at Niagara, but, whereas that is distributed among hundreds of towns and used for manufacture, lighting, tramways, and railways, this is being used at only two factories which are devoted to a single group of products.

The business of the company that owns this enormous power and has a capital of £8,000,000 is the capture of nitrogen from the atmosphere, and its conversion into artificial manure and other useful substances. Air is passed through electric furnaces, when a portion of the oxygen and nitrogen of which it is composed combine together. The greater proportion of this compound is absorbed by lime water, forming calcium nitrate, a valuable plant food, of which nearly 100,000 tons were produced last year. So smiling gardens and fields in various parts of the world owe their fruitfulness to the operation of a waterfall thousands of miles away.

Another artificial manure containing nitrogen, as well as calcium carbide, which is used for producing acetylene gas, is being manufactured in electric furnaces at Odda, on the Sondfiord. Some eight or nine miles away is a large lake, trapped and half hidden among the mountains. A dam has been erected across the narrow cleft through which the river flows, and a power-house has been built at Tyssedal. The electric current produced here is carried on tall poles to Odda, where it drives the

furnaces and does all the work of a large factory which has sprung up like magic on the side of the fiord. The wandering tourist who saw the place ten years ago, and who was charmed by its solitude, would find to-day a busy hive of industry, with all the modern machinery

*By courtesy of* *The Metropolitan-Vickers Electrical Co., Ltd.*

GENERAL VIEW OF THE TYSSELALDENE POWER-HOUSE.

and organisation to be seen in an English works. He would, perhaps, not be surprised to learn that the whole concern was due to the enterprise of an English Company.

To recount the tenth part of the water-power stations in the Scandinavian Peninsula would require as much space as has been allotted to the whole of the Section. Only a few of the rivers, lakes, and falls have so far been

utilised, but, as we have seen, huge factories have arisen and towns have sprung up with marvellous speed. The towns are being provided with electric light and electric trams, and a large and increasing proportion of the Swedish State Railways are being worked by electricity. In hardly any country at any time in the history of the world has so rapid a change been made.

The neighbouring kingdom of Sweden is even richer in waterfalls of large size than Norway. The little patches of blue on the map tell you of scores of lakes lying in the hollows of the mountains, and from every one there is a sort of spout which is filled with a roaring torrent when the spring sun begins to attack in earnest the piled-up snows of winter. As in eastern Canada, the need for power to cut up the logs from the forest-clad slopes has always led to an extensive use of water-power ; but it was only about twenty years ago that the Government began to appreciate the importance of this source of wealth.

Since then, they have set up a State Waterfalls Board, to establish and control water-power stations in various parts of the country. It has been estimated that the available energy from Swedish waterfalls exceeds ten million horse-power for from six to nine months in the year, and that even in winter about 2,500,000 horse power could be obtained. Seventy-five per cent. of this would be produced in Northern Sweden, fifteen per cent. in the province of Zealand, and ten per cent. in Götaland. In 1911 only 600,000 horse-power was obtained, and only 340,000 horse-power was used for generating electricity.

The most wonderful station in the country is at Trollhättan on the River Göta. In the hills beyond lies Lake Wener, 2,180 square miles in area, the third largest lake in Europe, which empties itself through the channel

of the Göta into the sea. Though no more than 144 feet above the sea-level, a fall of 108 feet occurs in a short distance, mainly in a series of cascades which have received the name of the Trollhättan Falls. Above and below this point are other rapids, which it is intended to use. In the dry season, 11,520 cubic feet of water pass per second, but, when the river is in flood, this rises to 32,400 cubic feet a second. By throwing a dam across the river at the point where it leaves the lake it is calculated that 200,000 horse-power will be obtained, but at present the engineers are contented with 80,000.

The power-house is situated below the rapids, and the water is brought from a point above. At the top of the first fall a regulating dam controls the level of the upper part of the stream. At a point on the east bank, 380 feet above this, is the intake, or mouth, of the feeder canal, which is 1,418 yards long. From this the water passes to the turbines, nearly 200 feet away, through eight large conduits, each fourteen feet in diameter, and three smaller ones, four feet in diameter. The turbines themselves are of enormous size. They are enclosed in steel casings, from sixteen and a half feet to eighteen feet in diameter, and weigh about 120 tons each.

A portion of the electric current which is produced is reserved for the State Railways, and the rest is sold to manufacturers in the neighbourhood. A large amount is taken by Gottenborg, which is the largest port in the country.

## CHAPTER XXVI.

### Power from Alpine Snows.

Is there any area of equal size in the whole wide world where man is more richly provided with water-power

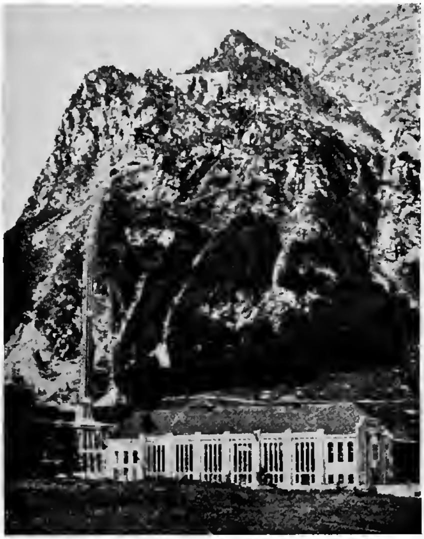
than in Switzerland? In the winter the snow falls thickly on steep slopes, and the glaciers receive a fresh supply at their source, and when the summer comes again the mountain streams splash down through steep gullies in roaring torrents. Everywhere this water is being brought under control, and a power station is almost as familiar a feature of the valley as a church or a school. The domestic industries carried on in the homes of the people are now being supplemented by factories; these derive their power from water and electricity instead of coal, so that the grime of the town is avoided, and the worker can still enjoy the pure air and clear skies of his mountain home.

The enormous power waiting to be utilised has long been known. Forty years ago, when the earlier Alpine tunnels were being driven, water-wheels were employed to drive the machinery for compressing air for the rock-drills, and for ventilating the workings; but the trains were drawn by steam locomotives. Now, electricity is used in all the tunnels and on several of the lines connected with them, and steam is slowly but surely being displaced.

A good example of a Swiss hydro-electric works is that on the Löntsch River. The drainage area, of about 31,652 square miles, is all Alpine mountain land, largely covered with ice and snow. Like all streams that depend on melting ice and snow for their supply, the volume varies very greatly with the season. In February the flow is only forty or fifty gallons a second, but in June it rises to about 3,000. By erecting a dam, 754 feet long and sixty-nine feet high, across the valley, a lake, 504 square miles in area has been formed, and this supplies water to the power station, over a thousand feet below, where 36,000 horse-power is produced.

The supply-pipe starts from the north bank of the lake

and is cut through solid rock for about two and a half miles; the water is then conveyed through three welded steel pipes which follow the slope of the hillside for nearly a mile down to the power-house. In this there are six Pelton Wheels, and upon the runners of each the water plays through two nozzles with a velocity of nearly twenty feet a second. The diameter of the jets is five inches, and of the runners nearly seven and a half feet.



ELECTRICAL WORKS AT LÖNTSCH.

Another interesting station is that near Lucerne. The water is taken from the river Erlenbach, and conveyed through a tunnel to a storage reservoir capable of holding 15,500,000 gallons. From this point it passes through two steel pipes, nearly 700 yards long, and three feet in diameter, to the power-house, 1,000 feet below. Here Pelton Wheels are used to generate electricity, which is transmitted to Lucerne and its neighbourhood, to Engelberg and several villages in Niddemwald, to an electric railway, and to an electric works at Kerns in Obdemwald.

Not only in Switzerland itself, but also in Northern Italy, and Southern Germany, the same kind of development

is going on. Thus a station at Brusio supplies power to the Bernina Railway, the city of Milan, and many towns in the plain of Lombardy. The Rhine, which, above Basle, flows westwards along the German-Swiss frontier, is tapped at Schaffhausen, Lanfenburg and Rheinfelden. The town of Basle is also supplied with power from Wangen on the River Aar. Steps have been taken to utilise all the available water-power in Bavaria, and both Munich and Nuremberg have commenced operations.

If we turn again to that part of Switzerland bordering on Italy, we find that the river Ticino, which flows through Lake Maggiore, has been harnessed, and there is another station at Biasca, near by. The town of Berne and the railway which runs from it through the most recent of the Alpine tunnels—the Lotschberg—are supplied with power obtained from Spiez, on the Lake of Thun.

The places mentioned produce well over 200,000 horse-power and are giving rise to chemical works in which substances like aluminium, calcium carbide, and nitrogenous manures, which require a plentiful supply of cheap electricity, are being manufactured in enormous quantities. On every hand the railways which convey passengers and the products of the factories are being driven to an increasing extent by electrical power. Slowly but surely, the habits and customs of the people are changing, and the solitude of remote Alpine valleys is vanishing before the activities of industrial life. .

## CHAPTER XXVII.

### Water Power in the Scottish Highlands.

It would be a pity if an English book could contain no example of the use of falling water in the mother country,

*By courtesy of* *The British Aluminium Co. Ltd.*

INTERIOR OF THE POWER STATION AT KINLOCHLEVEN.

and fortunately such an omission is unnecessary. For there is a station in Scotland which, though not among the largest in the world, is of quite a respectable size. Of course, it is no use looking in England for examples. Most of her important streams are navigable, and the peaceful flow which serves ships offers little opportunity for obtaining power. The rivers of most countries can be made to serve either as water-ways or as prime movers, but not as both. They cannot be temperate and riotous at the same time.

To come to Kinlochleven. In 1901 and 1904, powers were obtained by Act of Parliament to utilise the rain that falls on the western slope of Rannoch Moor, which slopes down to the shores of Lock Leven. This forms the basin of the River Blackwall, which drains the waste waters of a seventy or eighty-inch rainfall from fifty-five square miles of land. Across the valley was built a dam, 3,112 feet long and eighty-six feet high, of stone set in concrete. Behind this wall of masonry there is now a lake seven and a half miles long and half a mile wide, holding 20,000,000 gallons of water.

For three and a half miles the water is led in a concrete trough, eight feet wide and eight feet deep, to a reservoir holding 300,000 gallons, and from this it flows through six welded steel tubes, each thirty-nine inches in diameter, and one and a quarter miles long, to the Pelton Wheels. The fall is 935 feet, and the pressure of the water at the power-house is 406 lb. per square inch. The 30,000 horse-power is employed by the British Aluminium Company to obtain the beautiful, light, silvery metal which lies hidden so securely in clay. Sixty years ago the price of this metal was £28 a pound, and could only be used for trinkets and other small articles. But a method of preparing it cheaply in electric furnaces has been

discovered, and a pound can now be purchased for a small sum. Not only small ornaments, but cooking utensils, and the large vessels required in breweries and chemical works, are now made of it. It will probably surprise you to know that the clay which sticks so persistently to your boots contains from ten per cent. to twenty per cent. of aluminium, and the fact that a works using 30,000 horse-power has been erected to obtain it will show you how difficult it is to extract. As a matter of fact, the difficulty is so great that only a special variety of clay, called *bauxite,* is used.

Though this works at Kinlochleven is as far as we can go in fact, it may well give a start to the imagination. There are hundreds of thousands of acres of mountainous land in Scotland which is too poor to raise crops, but is just the kind of country in which the great water-power industries of the world have been established. Narrow valleys, swiftly running streams, and a heavy rainfall are just the conditions needed to obtain power from falling water; and, though raw materials would have to be brought from a distance, this is so even in the case of industries established on or near coal-fields. It is just possible that, as the black mineral which lies so far beneath the surface becomes worked out, men will turn to the waste places of the north, and establish homes and busy workshops in valleys which the sportsman, the tourist, and the shepherd now call their own.

# SECTION VI

## THE USE OF HIGH PRESSURE WATER.

### CHAPTER XXVIII.

### Water Pressure.

WHEN we speak of high pressure water we do not mean a trifle of two or three hundred pounds on the square inch, but of seven or eight hundred or a thousand. The water supply of most towns is between fifty and a hundred pounds on the square inch, and is obtained, as you have already learnt, by allowing it to flow from a reservoir from one to two hundred feet above the town's level. But in shipyards and steelworks the cranes, presses, and many other machines are worked by water at the higher pressures which have been mentioned; and it will probably surprise you to be told that in London, Birmingham, Manchester, and Liverpool, water at this pressure is laid on in many of the streets. In London alone there are more than 170 miles of strong pipes carrying water at 750 lb. per square inch.

For whatever purpose high-pressure water is used the demand for it will vary considerably. At one time a large number of machines may be at work, and at others hardly any at all. No air vessel will be elastic enough to take up the slack produced by such variation, and no open reservoir, from 1,500 to 2,000 feet high, can be constructed so near to the workshops as to respond instantly to the call for more or less water. So an arrangement called an *accumulator* is used. But before

this is described it will be a good plan to talk a little more about water-pressure.

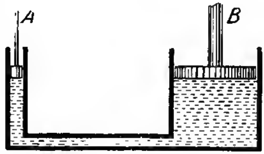
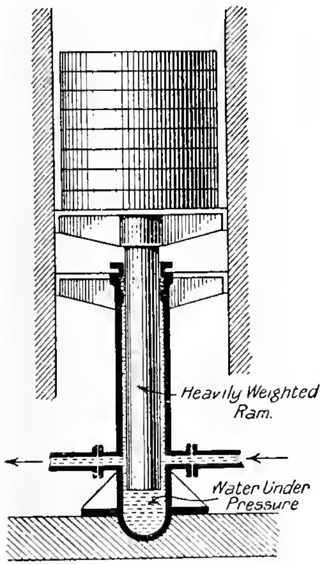



DIAGRAM TO ILLUSTRATE WATER-PRESSURE.

There is an important scientific principle which states that liquids transmit pressure equally in all directions. If a liquid is contained in a closed vessel of any shape, such, for example, as is shown in the sketch, a pressure of one pound on the square inch applied to the piston at A, will be felt on every square inch of the vessel. It will be clear, therefore, that if the piston at B is two square inches in area the total pressure upon it will be two pounds.




HYDRAULIC ACCUMULATOR.

Suppose now the piston at A moves downwards one inch under a pressure of one pound. Since water cannot be compressed (except ever so slightly) one cubic inch of water is displaced, and the piston B moves up half-an-inch. If the areas of the pistons be one square inch and ten square inches then a pressure of one pound on the smaller one will produce a pressure of ten pounds on the larger one ; but if the smaller one moves downwards one inch, the large one will only rise by one-tenth of an inch. Evidently then, very small forces can be converted

into very large forces by means of liquids. At the same time a relatively large movement of the smaller forces corresponds to a relatively small movement of the greater force.

Now let us look at the accumulator. It consists of a strong vertical tube into which a rod of metal, called a ram, fits closely. This ram is heavily loaded, so that when water is pumped into the tube or barrel the ram is forced upwards, but continues to exert a steady pressure upon the water. Suppose the ram is four inches in diameter, the area of the end which presses upon the water will be just over twelve and a half inches. If the ram is loaded with a weight of five tons or 11,200 lb., the pressure per square inch will be—

$$\frac{11200}{125} = 900 \text{ lb. approximately.}$$

If water at 1,000 lb. on the square inch presses upon a piston of 100 square inches in area, the total pressure will be 100,000 lb. or nearly forty and a half tons, and to obtain this the piston need only be just over eleven inches in diameter; with a larger piston a correspondingly large force can be applied, and some of the machines used for bending and shaping iron exert a force of 12,000 tons.

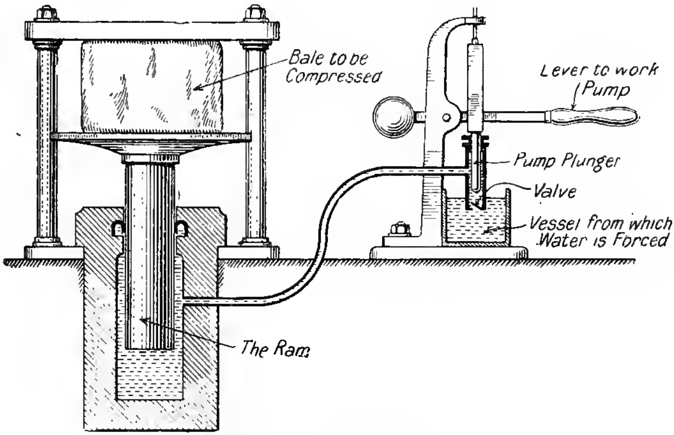
## CHAPTER XXIX.

### Hydraulic Presses and Lifts.

HYDRAULIC or Bramah presses, as they are called, are mounted in a very strong frame. At one end is a heavy steel casing containing a hollow space fitted with a plunger or ram. The other end of the ram forms a sort

of table upon which the object to be compressed can be laid. Above it is fixed a block against which the object is squeezed. This is a vertical press, but they are often arranged so that the squeeze is exerted horizontally.

The hydraulic press is one of the most valuable tools which the steel manufacturer possesses. It acts more slowly than the steam hammer, by which the hot pasty




THE BRAMAH PRESS.

metal is subjected to furious blows ; but the pressure is applied more uniformally, and the steel can be bent to the exact shape, or compressed to the exact size required.

But there are many uses outside of iron and steel works. Cotton and other soft goods which ordinarily take up a great deal of room are compressed into solid bales for shipment. You probably know that cargo is charged according to the space it takes up, 100 cubic feet being reckoned to the ton, and if soft goods in bales were

not compressed into the smallest possible volume, the carriage would be greater, and the cost of manufactured goods higher, than they are now.

Hydraulic power is used very largely for lifts and cranes, though the former are now frequently worked by electricity. When water is employed the method is always to force out a plunger by admitting water at high pressure behind it. The simplest kind of lift is the hydraulic jack, for lifting heavy weights through short distances. This has its own pump and a small reservoir of water in the lower portion of the stand, which is used over and over again. The plunger or piston of the pump is very small and is worked by a lever which gives an additional advantage. Thus, suppose the arms of the lever are in the ratio of ten to one, and the pump plunger is half an inch in diameter, a force of 20 lb. on the lever would give a force of 200 lb. on the plunger and as the area of this is just under one-fifth of a square inch, the pressure of the water would be 1,000 lb. per square inch. If this acts on a ram about 1.7 inches in diameter, the lifting force would be a ton. With some jacks a man can lift a ton or more, with ease.

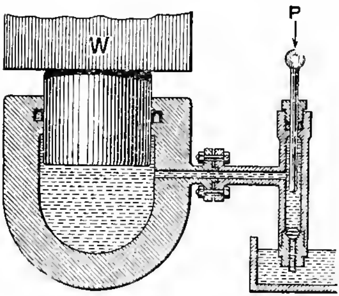


DIAGRAM OF A HYDRAULIC JACK.

After the jack has been used a tap has merely to be turned to allow the water to run back from the upper to the lower chamber. Nearly all the cranes that one sees at the docks in the great ports of the world are

worked by high-pressure water. They are generally capable of dealing with loads of from five to twenty tons. But it is in shipyards that the largest lifting appliances are found. Some of them will pick up, sling round, and deposit burdens of 250 tons, and though these are not common there are many constructed to carry 150 tons.

And while we are speaking of shipyards, it will not do to miss the hydraulic rivetters. They look like the claws of a monster crab, as they are slung in the air by a huge crane. The length of the gap may be as much as twelve feet. At the ends of the claws are the two heads between which the rivet is held. One of these is fixed and holds up the head of the rivet; the other is the plunger or ram which is forced out by hydraulic pressure and slowly but surely forms a head on the other end. If you have ever seen these at work in the boiler shop, the shipyard, or on a big bridge, and compared their speed and quietness with the bustle of the men who close the rivets by hand, you will realise the amount of human energy they save.

Those who have read the volume on *The Mastery of Earth* will remember how rock drills, driven by high-pressure water, were used to drive the great Alpine tunnels. Again, in mining, and especially in hydraulic mining, where a powerful jet is used to wash down the gold-bearing gravel, the force exerted by water at high-pressure is irresistible. But the most wonderful use, perhaps, which has ever been made of a jet of water was in the construction of the Chicago, Milwaukee, and St. Paul Railway. When the line reached Topographer's Gulch, a deep ravine in the Cascade Mountains, the engineers had to consider whether they would build a bridge or an embankment, or go round the valley. At

this point the depth from the line was more than 280 feet, and the distance to be spanned about 800 feet. A bridge would have been expensive because the mountain sides and the valley were soft and gravelly; and the building of such an embankment in the ordinary way would have required an enormous amount of labour.

Finally, it was decided to make the embankment by washing the sides of the mountain into the valley. Powerful pumps were erected and huge jets of water were directed against the soft material. The stream of mud and gravel was directed into wooden troughs which distributed it where it was required. And as the hillsides were worn away a ridge of land reared itself up in the valley, along which, at last, the metals were laid.

There is a rather interesting example of the use which is made of the power of liquids to withstand high pressure, in big guns. When a big gun is fired it kicks. The shell is forced out by the expansion of the hot gases from the exploded cartridge, and the gases, finding the shell in their way, tend to force the gun backwards. Every rifleman knows that if he does not hold his weapon closely to his shoulder the recoil is liable to bruise him badly. Even in a revolver or pistol the existence of the kick is shown by the tendency for the end of the barrel to move upwards, and for the shot, therefore, to pass over the object at which it is aimed.

In the case of a big gun firing a shot which weighs anything from a hundredweight to more than half-a-ton, the recoil is very powerful, and if the gun and its carriage were fixed rigidly something would give way. In some of the earlier guns the carriage was mounted on wheels, and stood for firing on rails at the bottom of an incline. When the gun was fired, the carriage ran backwards uphill, and then returned to its original position.

The modern method is for the gun to rest on a slide. A piston attached to the gun fits in a cylinder containing liquid and attached to the carriage. When the gun is fired the piston is forced into the cylinder and drives out the liquid into another compartment through a number of small holes. The resistance offered to the passage of the liquid causes the cylinder and piston to act as a hydraulic buffer between the gun and carriage, and prevents injury to the latter.

# SECTION VII

## THE THREE STATES OF MATTER.

## CHAPTER XXX.

### Ice, Water, and Steam.

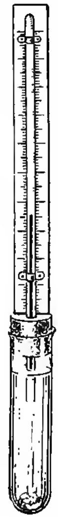
EVERYTHING that we can see, hear, smell, taste, or feel is called matter. This includes the stuff of which earth, and sea, and air are composed. Light, heat, sound, electricity are not matter, though they produce effects on the body or some of its organs which enable them to be detected. But you cannot weigh a note of music, or a current of electricity; the brightness of light and the degree of heat or cold cannot be measured by the balance.

It is quite possible that, as scientific knowledge advances, we shall not be able to distinguish so sharply between matter and non-matter; but for the present we are content to say that matter is that which can be measured and weighed.

Some of the stuff with which we are surrounded is solid, some is liquid, and some is gas. Probably every one knows that, if a solid is heated strongly enough it will melt, and if a more intense heat is applied it will be converted into a gas. There are a few solid substances —iodine, for example—which pass directly into the gaseous condition. It is an interesting and important fact that water, the commonest and most widely distributed substance in the world, is familiar to every one, or, at least, to every one who lives outside the tropics,

in all three forms. Of what other substance could you say that you had walked on it, drunk it, and breathed it, all within a few minutes ?

Let us look a little more closely into the relations between the solid, liquid, and gaseous forms of water ; because if you really understand these you will hold the key to many operations of Nature and man. First, whenever water changes into ice, does it become heavier or lighter, or remain the same, bulk for bulk ? Does ice float or sink ? If we have any doubt on this point make the experiment on the first favourable occasion. It will not be necessary to wait for the winter ; most fishmongers keep a supply of ice, which they will sell you at a few pence a pound.



EXPERIMENT TO MEASURE CHANGE OF VOLUME WHEN ICE MELTS.

If you want to know exactly what change of volume occurs, here is an experiment that will tell you. A piece of ice is placed in a glass tube, which is then filled up with petroleum (paraffin oil). A cork, with a narrow tube having a scale at the back, is then quickly fitted in, and the level of the liquid in the narrow tube watched as the ice melts. The measurements which must be made in order to give you a numerical value of the change of volume form an admirable exercise in arithmetic—quite easy, and so useful, that it may well be left to you to work out for yourself.

When you have satisfied yourself upon these points, it will be interesting to refer to Chapter XXIII, and see how advantage is taken of such knowledge in removing ice from the water of the Niagara River, before it enters

the turbines. It is also interesting to make an estimate of the proportions of an iceberg above and below water. Again, you can ask yourself why a pond freezes over on the surface, rather than along the bottom, and a host of other interesting questions.

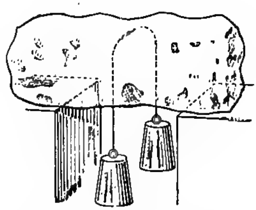
The experiment may also be carried out in the opposite direction, starting with water instead of with ice, and lowering the temperature until the water freezes. To lower the temperature the tube may be immersed in a mixture of ice and salt, the action of which will be explained presently. It will be found that as the water becomes solid an increase in volume occurs. Here we have an explanation of the bursting of water pipes in winter. The damage is done when the water freezes, but is not discovered until a thaw causes the ice, which fills the tube and sometimes even protrudes from the opening, to be again turned into water. The plumbers are busy not at the beginning of a frost, but at the end of it.

Now, it is quite evident that for a given weight of water at the freezing-point, there is one volume which corresponds to the solid condition, and another to the liquid. What will be the effect of squeezing a piece of ice? Surely the pressure will tend to reduce the volume to that corresponding to the liquid condition, and some, at least, of the ice will be melted. You can check this by taking two pieces of ice, pressing them together and then pulling them apart. It will be found that they stick a little, and the explanation is that the

EXPERIMENT TO SHOW THAT PRESSURE MELTS ICE.

ice at the points of contact has been melted by the pressure, forming a thin film of water, which freezes again as soon as the pressure is released. This experiment, of course, is best done on a day when the temperature is slightly below the freezing-point.

A more satisfactory proof is given by the apparatus shown on page 184. The metal block has a halfpenny placed at the bottom of the screw-cavity, and the latter is then partly filled with water which is frozen by standing the block in a freezing mixture. When the whole of the water has been converted into ice the screw plug is forced in tightly, the block is inverted, and the screw is then removed. It will be found that the halfpenny is now close to the screw plug, whereas it was originally separated from it by a block of ice.



A COPPER WIRE CUTTING ITS WAY THROUGH A BLOCK OF ICE.

There is a still more interesting experiment to illustrate this property which any one can perform without special apparatus. A block of ice is supported at the ends, and from the middle is slung a weight or heavy stone by a piece of thin copper wire. In time the wire cuts its way through the ice and the weight falls to the ground, but the block still remains whole. The pressure under the wire causes the ice to melt; the water flows round the wire and freezes again across the top of it. The layer of re-formed crystals between the two halves of the block can be seen distinctly after the experiment is over.

But one of the most wonderful properties of ice is the fact that it will flow, not like water, but like a thick treacly liquid. The ice which forms on the top of high

mountains slips down the sides into the valleys and forms rivers of ice. By fixing posts in a straight line across a glacier and making observations from week to week, it has been found that, as in the case of a river, it flows more quickly in the centre than at the sides. Clearly, too, it drags along the bottom, and as the top tends to roll over, huge cracks, called crevasses, are formed across the surface. These are sometimes hidden by a covering of snow which gives way when any pressure is put upon it. As they are often many feet deep they form one of the greatest dangers to travellers and many lives have been lost in their cavernous depths.

In the polar regions the ice which forms on the land sloping to the sea also slips downwards. Here it is buoyed up by the water, and enormous masses are broken off, to be carried away as icebergs by the ocean currents. Many a fine vessel has been wrecked, and thousands of lives have been lost by collision with these floating mountains of ice. In the North Atlantic they drift into the tracks of the steamers about May, and the course is altered a few degrees to the south in order to avoid them. A special steamer is now engaged as an ice scout to keep a look-out for bergs and to report their position to passing vessels.

To go back for a moment to the "flow" of ice in glaciers. The tendency of some apparently solid bodies to flow like water is not uncommon. "Cobbler's wax" is so brittle that a sharp tap will break it into fragments, yet a lump left to itself for a long time gradually flattens out as though it were a liquid. A good experiment is to make a model flight of stairs in wood or cardboard, and to place several pieces of cobbler's wax on the top stair. In the course of a few months it all spreads out and flows downstairs in a continuous sheet.

Suppose now you place a number of pieces of ice in a vessel containing a thermometer, and set it in a moderately warm room, so that the ice melts slowly. The thermometer may indicate a temperature below freezing-point if the ice has been collected during a sharp frost and used immediately; but it soon rises to freezing-point and remains so until the whole of the ice has melted. When this has occurred, the thermometer indicates a slowly rising temperature, which is quickened if a lamp or a gas flame is placed underneath.

As more and more heat passes into the water, it becomes hotter and hotter until you can no longer bear your hand in it. Finally, bubbles form and rise to the surface, while clouds of vapour appear above the vessel. At this point the mercury in the thermometer becomes stationary at the "boiling-point." No matter how you try to raise its temperature, the water only boils faster, and the thermometer indicates the same degree of hotness. The result remains the same whether the bulb of the thermometer is above or below the surface of the liquid, so long as the water is pure; but if salt or any other substance is present in the water the temperature of the boiling water is higher, though that of the steam remains the same. If all the water is boiled away, the thermometer again begins to rise.

If the thermometer has what is called a Centigrade Scale, the freezing-point will be marked 0°, and the boiling-point 100°; these are called the "fixed points," because they correspond to the temperatures at which ice melts and water boils. When the heat is pouring into the melting ice it is causing a change of state, and when it is pouring into boiling water it is causing another change of state. Until these changes are completed, the heat cannot produce any further rise of temperature.

## CHAPTER XXXI.

### The Relation between Temperature and Change of State.

A GREAT many important facts arise out of the amount of heat required to convert ice into water, and water into steam. The heat required to melt completely a pound of ice at freezing-point is eighty times as great as the amount required to make the water so formed one degree hotter; while the amount required to convert a pound of boiling water into steam is nearly 540 times as great. You will understand now that, though the temperature of a pond may fall very rapidly, it takes a long time to freeze over, and though water may be very quickly raised to the boiling-point, a long time is required for it to boil away.

When steam changes to water and water to ice, exactly the same quantity of heat is given up by each pound as was necessary for the change in the opposite direction. There is, as it were, a storage of heat during the change, from solid to liquid, or from liquid to vapour; and it is for this reason that ice is so valuable as a cooling agent, and steam for heating.

But, even for an ordinary change of temperature, water requires a larger quantity of heat than any other substance. Not only, therefore, does it absorb heat more slowly, but it gives it out over a longer period. On this account it has a very important effect upon climate. An island, or a place near the sea coast, is never subject to such extremes of temperature as a place far away from the sea. The interior of a continent is rapidly baked by the summer heat, and as rapidly cooled

by the winter's frost; while on the coast the water stores up the heat of summer and yields it again to mitigate the severity of winter.

Let us now consider in a little more detail the effect of heat upon water. It is, of course, not necessary to boil water to cause it to pass into vapour. The puddles left by every shower of rain soon disappear, especially if there is a warm, dry wind. The air itself invariably contains moisture, a fact which is shown when a glass or cup is filled with cold water. The outside is immediately covered with a thin film which has been laid gently and silently upon it by the surrounding atmosphere. How this takes place will be considered later; here it is merely necessary to point out that water at all temperatures, and even ice to a very slight extent, tends to pass into invisible vapour.

A solid can be changed into a liquid, and a liquid into a gas, and a gas has the property of infinite expansion. If the smallest measurable quantity of a strongly smelling substance be liberated in one corner of a large room, it can soon be detected in every part. A minute drop of water, introduced into an empty vessel, evaporates and fills the whole, so that in every cubic inch of it there is water vapour. Now what sort of structure would permit of this indefinite expansion? Is the gas a sort of continuous thin jelly, or is it composed of separate particles which simply open out or close up according to the space they have to fill?

Scientific men believe that the last explanation is the more correct one, and that all bodies are composed of minute particles called molecules, which may themselves be groups of still smaller indivisible particles called atoms. These molecules are never still, except, perhaps, at a temperature far below that of the polar regions, though

very nearly attained by man in his laboratories. The higher the temperature, the more energetic do they become; and, as the body, of which they form the substance, increases in size, so do they have more room in which to perform their movements.

The application of heat to water, then, increases the rate of movement of the molecules. Their velocity is never uniform, but at any given temperature the average velocity of all of them is constant. They are prevented from flying apart by an attraction which they have for one another; but occasionally one of the more lively ones comes to the surface and breaks away from his fellows. This is the process of evaporation.

Not only does a mutual liking for one another tend to keep the molecules within the liquid, but the pressure of the air upon the surface has the same effect. When the tendency of the molecules to escape becomes equal to the pressure of the air over the surface, the liquid boils. Water in an open vessel on the top of a mountain, where the pressure of the atmosphere is less than at the sea-level, boils at a lower temperature. It will not make tea, or cook potatoes; for these purposes a closed vessel must be used.

When a liquid is raised to the boiling-point, the more energetic molecules, which are then very numerous, escape rapidly. Pouring more heat into the liquid merely increases the number of molecules with the energy necessary for escape. But, if the free molecules cannot escape, then pressure and temperature both rise.

At this stage, let us approach the matter from another point of view.

The same piece of apparatus that was used for measuring the expansion of water on freezing, can furnish you with other interesting facts. Thus, if you watch

carefully the height of the column of petroleum in the thin tube, you will find that when the whole of the ice has melted, the expansion ceases, and as the temperature rises there is a small contraction. After that, the volume increases until the water boils, though you cannot in this experiment carry your observations quite so far.

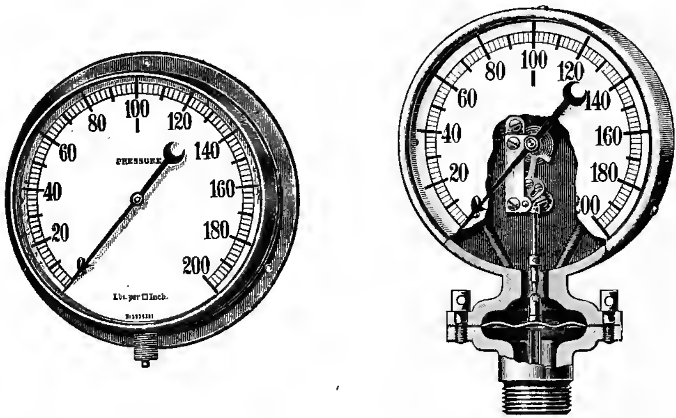
The contraction and subsequent expansion of water shows that at one particular temperature—about 4° on the Centigrade scale—there is a greater quantity of water in a given volume than at any other temperature. In other words, water at that temperature is at its maximum density. Consider now what happens when a pond freezes. As the air becomes cooler, the temperature of the surface water falls until it approaches 4° C., and then, as it is heavier than water above or below that temperature, bulk for bulk, it sinks to the bottom. This goes on until the temperature of the whole pond is reduced to that of maximum density, when the surface becomes gradually cooler until it freezes over. The crust of ice protects the lower layers from the cold air above, so that the water of a frozen pond is nearly always above freezing-point, and fish can live in it until the ice melts again.

## CHAPTER XXXII.

### Safety Valves and the Steam Engine.

The changes in volume which have been described, however, are trivial beside that which occurs when water is converted into steam. By experiments which cannot be described here, it has been found that a cubic foot of water at the boiling-point produces 1,648 cubic feet of steam. If the vessel in which it is boiled is closed,

and no means of escape for this steam is provided, the pressure rises until it may burst the boiler. For that reason every boiler for producing steam under pressure is fitted with a safety valve. This is simply a valve which is held down by a weight or a spring, so that when the pressure in the boiler reaches a certain amount, it rises and permits the steam to escape.



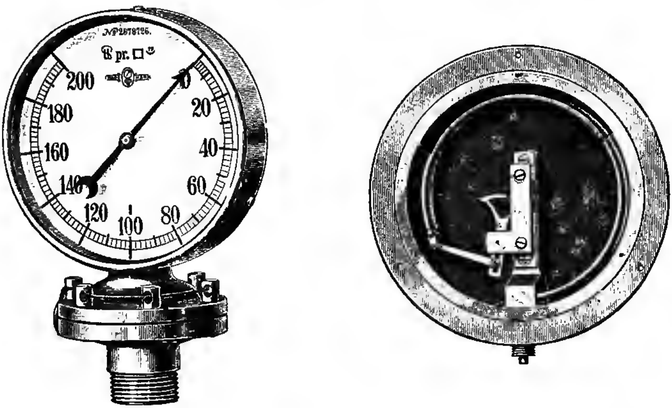

*By courtesy of* *The Budenberg Gauge Co., Ltd.*

A BOURDON PRESSURE GAUGE.

All boilers—and, in fact, all vessels which are to contain liquids and gases under pressure—are fitted with gauges to show at any moment what the pressure is. Two forms are in common use, both being very simple in construction. In the Schäffer and Budenberg pattern, a pipe, leading from the boiler, is closed by a disc of metal clipped at the edges. The disc is not flat, but is stamped with a number of circular troughs and ridges. The effect of pressure on one side is to straighten these out and bend the whole plate into the shape of a shallow bowl. The

greatest movement is, of course, at the centre, and at this point the plate is attached to a small rod, which acts on a lever and causes a pointer to turn round.

In the Bourdon Gauge, the steam is led into an oval tube bent into a curve, and closed at the end. Such a tube has a smaller volume than a straight one of the same length, and the pressure inside tends, therefore, to




*By courtesy of* *The Budenberg Gauge Co., Ltd.*

A SCÄHFFER GAUGE.

straighten the tube. As the closed end is linked up to a pointer, any alteration in the curvature causes the pointer to turn and indicate the pressure on the scale.

If water is heated in a closed vessel, fitted with a thermometer and a pressure gauge, there will be a steady rise of pressure and temperature until the point is reached at which the safety valve blows off. No matter how many times this may be tried there is always a definite pressure for each temperature. As the temperature rises, more and more water must be converted into

steam, and the increase of pressure is the result of a large quantity of steam being compressed into the same space. If the space above the water is connected through a pipe with an empty vessel, the steam immediately expands until it fills the new space.

The expansibility of steam is the property which renders it so useful in the steam engine. You will, no doubt, like to know how a steam engine works. The principal part is the cylinder. This is almost explained by its name, but will be quite clear from the diagram and what follows. It contains a tightly fitting piston which is moved backwards and forwards by the pressure of the steam which is admitted at each end alternately. The admission of steam is controlled by the slide valve or some other form of valve; the steam is not allowed to enter during the whole stroke of the piston. When this has moved through $\frac{1}{5}$, $\frac{1}{4}$, $\frac{1}{3}$, or $\frac{1}{2}$ of its full distance, the slide valve is closed and the steam does the rest of its work by expansion.

It will easily be seen that, as the steam expands, its pressure falls, and from what we have learned from the relation between pressure and temperature, the temperature also must fall. The temperature multiplied by the weight of steam used is a measure of the work done, for the steam engine is really a heat engine, and the steam is merely used as a convenient substance to transfer the heat from the boiler to the engine.

The piston has, fixed at its centre, a rod passing through a steam-tight gland in the cylinder cover, and terminating in a block or "crosshead" which slides between guides. This is linked to the crank by a connecting rod and the to-and-fro motion of the piston is thus converted into the circular motion of the shaft. The valve by which steam is admitted to each end of

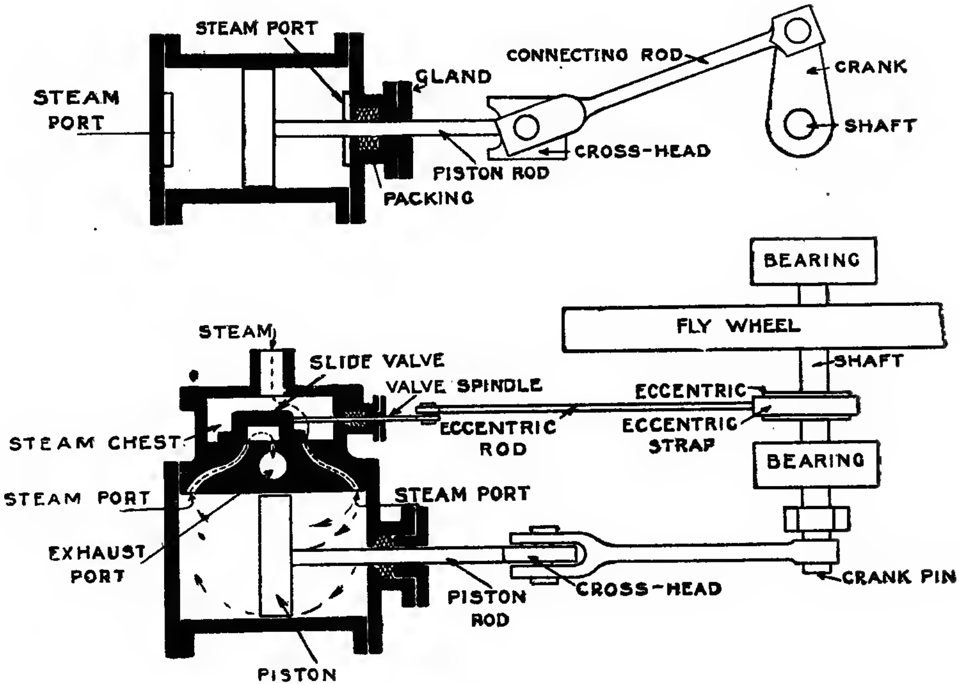



DIAGRAM OF A STEAM ENGINE.

the cylinder alternately, while the other end of the cylinder is put into communication with the exhaust passage, or "port," is moved by an eccentric, which is really a small crank. A disc is fixed on the shaft, which passes through a hole out of the centre—hence the name "eccentric." As the shaft turns the eccentric "wobbles," and this motion is transmitted to the valve by rods similar to those between the piston and crank.

For fuller information about the mode of construction and working of the steam engine, other books must be consulted. It was first made into a really useful machine by James Watt in 1769, and did more to alter the conditions and habits of life than anything else since the world began. It led to the growth of large factory towns on or near the coalfields, and it gave to the world the railway and the steamship.

## CHAPTER XXXIII.

### The Water of the Mist.

THE air, forming a vast envelope round the earth, is always more or less charged with invisible water vapour. Suppose a closed box is filled with dry air, and a drop of water is allowed to fall into it. The splash on the bottom remains for a short time, but, if the air is warm and the box large, it very rapidly dries up. This process can be repeated several times, each drop drying up more slowly, until the air refuses to take up any more. The air now is said to be saturated, and if the temperature falls, moisture is deposited as dew on the walls of the containing vessel.

Just as we found that in the case of steam there was a definite relation between the temperature and the

*Photo by* *Valentine.*

MIST ON THE HILLS.

pressure, so the air retains a definite amount of water vapour for each temperature. During the day, when the sun shines, pools, rivers, and seas give up to the air their more energetic particles; and at night, when the sun goes down, the temperature of the air falls, and every leaf and every blade of grass becomes covered with drops of dew. The term "Morning dew," so often written, is only partially correct, for the deposition of moisture begins when the sun goes down and continues throughout the night.

If the temperature is below freezing-point when the air deposits its moisture, the dew drops are replaced by crystals of ice. Leaves and branches are richly bespangled with hoar-frost, and the morning sun reveals the earth clad in a mantle of glistening white, strange and beautiful as Fairyland.

The cooling of the air near the ground leads to the formation of a mist, which can often be seen hanging over fields and low-lying ground. From the top of a hill, this faint, white cloud appears to fill the valley, and its surface seems to be in continual commotion. In a similar way, the clouds overhead are formed by currents of warm, moist air meeting with colder air and throwing out their water in myriads of minute droplets.

The mist is, as you know, soon dispelled by the warmth of day—at any rate, in the country; but what happens to the clouds that float so serenely in the upper regions of the atmosphere? "Float so serenely," did we say? Surely we should add, "Or scurry across in threatening masses which forebode a storm." The fate of the cloud is the fate of the droplets of which it is composed. If they are wafted into warmer or drier regions they disappear into their hiding-places once more as invisible vapour. But if their course takes them into cooler or

moister regions, then each one grows and becomes heavier until it splashes down in a storm of rain on the earth below.

The life-story of one of these aerial drops is a fascinating study. The question may well be asked : "Since water is heavier than air, why do not the clouds fall at once, instead of remaining suspended until the drops have grown ?" That is easily answered. Have you ever filled a glass jar with muddy water and noticed how long it takes for the finest particles to settle ? Long after the heavier grains found a resting-place on the bottom, the smaller ones remain buoyed up by the liquid, settling so slowly that their movement cannot be observed. Were it not for the friction upon their surfaces, all the particles would settle together ; if it is assumed that they are spheres, a simple calculation will show the importance of size.

The volume of a sphere is given by the formula—

$$\frac{4}{3}\pi r^3,$$

and the area of its surface by the formula—

$$4\pi r^2,$$

where $\pi$ is the ratio of the circumference of a circle to the diameter, and $r$ is the radius. The volume of a sphere of two inches radius is—

$$\frac{4 \times 22 \times 2 \times 2 \times 2}{3 \times 7} = \frac{704}{21} = 33{\cdot}5 \text{ cub. in. nearly.}$$

The volume of a sphere of one inch radius is—

$$\frac{4 \times 22}{3 \times 7} = \frac{88}{21} = 4{\cdot}2 \text{ cub. in. nearly.}$$

The surface of the larger sphere will be—

$$\frac{4 \times 22 \times 2 \times 2}{7} = \frac{352}{7} = 50 \text{ sq. in. nearly.}$$

The surface of the smaller sphere will be—

$$\frac{4 \times 22}{7} = \frac{88}{7} = 12{\cdot}5 \text{ sq. in. nearly.}$$

Now, while the volume of the smaller sphere is only one-eighth that of the larger, its surface is one-quarter the surface of the larger sphere. The smaller sphere has, therefore, twice as great a surface in proportion to its volume (which fixes its weight), so that the effect of friction will be much greater and the rate of fall will be very much reduced. And that is why cloud drops have to grow before they can fall as rain.

But there are more interesting discoveries to come. Every one knows that in the country fogs are rare, and in the towns they are frequent. More than thirty years ago Mr. John Aitkin showed that the most important cause of fogs is the presence of fine solid particles in the air, around which the water drops can form. This fact can be explained quite easily by the calculation we have just performed. Suppose a drop of water to enter dry air, and to be continually reduced by evaporation from its surface. As the drop becomes smaller its surface becomes relatively larger, so that evaporation becomes more and more rapid, until, when a certain degree of smallness is reached, the drop flashes off into vapour.

Now suppose the opposite change to be taking place, and imagine a quantity of air falling in temperature so that some water vapour must be thrown out. If the droplets first formed are below the limiting size which has just been described, they tend to flash off into vapour as soon as they are formed. But if there are tiny dust particles around which the moisture can condense, the explosive period in the infant life of the drop will be passed, and it can reach the full growth of a fog-particle or a rain-drop.

Air, which has been carefully freed of its dust, can be cooled, without any moisture becoming visible, several degrees below the temperature at which it would, in ordinary circumstances, deposit moisture. But, if a little dust is allowed to enter, a mist immediately forms.

Perhaps this is as far as you will care to go with me at present, though it is only the fringe of the knowledge that man possesses about the water in the air. Some day, perhaps, in another volume, we will make a more extensive journey and inquire what is going on in the heart of a thunderstorm.

## CHAPTER XXXIV.

### Salt and Water.

HARDLY any word in the English language is so frequently used and so little understood as the word "solution." The readiness with which many liquids take up a solid and hide it amongst their own molecules is one of the most striking facts of Nature. The liquid is apparently as liquid as it was before, and the solid can only be detected by the taste, smell, or colour, which it gives to the liquid that has, in very truth, swallowed it up. Often, indeed, the presence of the dissolved substance can only be recognised by chemical means. The only method of recovery is to boil the liquid away.

The presence of the solid has two important effects. On the one hand, the freezing-point is lowered, and on the other hand, the boiling-point is raised. If common salt, for example, is dissolved in water, the liquid may be cooled below the point at which water ordinarily freezes by an amount which depends upon the quantity of salt. This is why sea-water, which contains among other

things, common salt, does not freeze so readily as fresh water. The actual freezing-point is $-4°$ Centigrade.

When ice and salt are well mixed together they liquefy, because the temperature at which this is usually done is higher than the freezing-point of the mixture. On this fact depends the method of cleaning streets of snow by sprinkling salt over them. The liquid slush thus formed is intensely cold, and if the boots become thoroughly soaked with it, it causes a good deal of discomfort.

A solution of salt in water behaves very curiously when cooled. If the percentage of salt is less than 23·5, ice separates first until that percentage is reached, and then the salt and water solidify together. If the percentage is higher, salt separates first, until the same percentage is reached, and then the whole solidifies. These changes bothered early scientific men, but are now fairly well understood; their principles have been applied to metals, such as iron and steel, and alloys which behave as though they were solutions of one substance in another.

The lowest temperature that can be produced in this way is obtained with 23·5 per cent. of salt, which gives an excellent freezing mixture, suitable for scientific experiments or for making ice-cream. The chemical name of common salt is sodium chloride. An even lower temperature can be attained with either calcium chloride or magnesium chloride. The ordinary name for a solution of any of these substances is "brine," and brine is used to convey the cold from the refrigerator to the ice-tanks in the manufacture of ice, and to the storage-chambers on meat-vessels and in cold stores.

Now let us consider the effects on the boiling-point. The temperature at which a solution boils depends, again, on the amount of dissolved substance present,

and there is at least one common application made of this fact. A strong solution of calcium chloride can be made much hotter than water, and this was used to fill the foot-warmers which were in railway-carriages in the winter. On most railways nowadays the carriages are heated by steam.

Water dissolves some substances much more readily than others, and in most cases hot water licks up a larger quantity than cold. As the water is removed by boiling, the tendency is for the solution to become stronger. Even if the solution is weak to begin with, it is easy to reach the point at which some of the solid is thrown down. For this reason water containing much solid in solution is bad for steam boilers, which become covered with scale that has to be cleaned out.

If a hot, strong solution is allowed to cool, the dissolved substance often separates out in beautiful crystals. As hardly any two substances are soluble to the same extent, this enables the chemist to separate one substance from another. Very often the process has to be repeated many times, and the work requires great patience.

The study of solutions has now become a very large one, and even a very elementary treatment would carry us far afield. We can only say here that, to the manufacturing chemist, as well as to the user of steam boilers, the nature and amount of the substances dissolved in natural waters are matters of first-rate importance—matters of which, for the sake of his business, he cannot afford to remain in ignorance.

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